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TERRESTRIAL MAGNETISM AND ATMOSPHERIC ELECTRICITY

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CHAPTERS IN THE HISTORY OF TERRESTRIAL MAGNETISM

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I—ON THE DIRECTIVE PROPERTY OF A MAGNET IN THE EARTH'S FIELD AND THE ORIGIN OF THE NAUTICAL COMPASS

1—The science of Terrestrial Magnetism is based on the fact that a magnet, free to move about its center of gravity, tends to assume a position of relative rest in an approximately definite direction with respect to the geographical meridian and the vertical at the place of observation. That it should do so must be due to the existence of a field of force which is known as the terrestrial magnetic field [**1**], and the systematized knowledge of that field, of its variations in time and space, and of its relations with the subject-matter of other branches of terrestrial and cosmical physics, constitutes the science of Terrestrial Magnetism.

The object of these articles is to present a history, as complete as possible, of the development of this science. The method adopted will be that of collating the various accounts which have been given of the discovery of its fundamental principles and their gradual evolution into the form in which they are at present held. To assist the reader in forming his own conclusions, an attempt has been made to provide ample bibliographical references.

2—The first matter which arises for consideration in the history of the science is that relating to the discovery of the directive property of a magnet with reference to the Earth. By whom, at what date, and in what form, this was first recognized is now unknown, for the discovery was made in times long before the maintenance of careful scientific record. The investigation of this question has given rise to an extensive literature, but has led to few conclusions of a definite kind. Its treatment in standard works on magnetism is generally—and necessarily—confined to a brief statement which does not profess to be critical or discriminative, and for an adequate understanding of its many difficulties and obscurities we must examine the writings of those who have dealt with one or other of its numerous aspects. The matter practically resolves itself into an enquiry as to the origin or invention of the mariner's compass, and to the honor of this discovery several claims have been advanced.

3—The claim which goes furthest back in history is that made on behalf of the Chinese. It was first presented by Gaubil [**2**], Duhalde [**3**], Mailla [**4**], and Amiot [**5**]. It was repeated by Hager [**6**], Klaproth [**7**], and Biot [**8**], and has been supported or, at least, quoted by many later writers. In general terms it may be stated as follows. The ancient annals of the Chinese Empire contain passages which can only be construed as meaning that the directive property of a magnet in the Earth's field was known in China several thousand years ago; that in later ages there follows a succession of references indicating a constant tradition on the subject; that these gradually merge into others which mention the compass in its earliest form; and thus we reach the seventh or eighth century A. D., when this primitive instrument was employed for survey-

ing and navigation. It is thus contended that the compass is an adaptation in later times of a principle known to the Chinese for the last 4,500 years.

In examining the evidence in support of this claim, we have to distinguish between that which depends chiefly upon the mythological history of China and that which is gathered from the literature of more recent times.

With regard to the former, it is stated [**9**] that in 2634 B. C. the Chinese emperor Hoang-Ti was at war with a tributary prince named Tchi-Yeou, and that they fought a great battle in the plain of Tcho-luo. In order to escape defeat, or its consequences, Tchi-Yeou raised a dense fog which produced disorder in the imperial army—an anticipation of the smoke-screen of modern times. But Hoang-Ti constructed a chariot upon which stood the diminutive figure of a man with arm outstretched, and this figure being apparently free to revolve on its vertical axis, the arm always pointed to the south. By this means, the emperor was able to locate the direction of his enemy's retreat; Tchi-Yeou was captured and put to death. By the earliest European commentators on the Chinese annals—the Jesuit missionaries who went to China during the latter part of the seventeenth century [**10**]—it was at once inferred that the movable figure was actuated by a magnet, and this inference forms the basis of the claim now under consideration.

In the later Chinese literature, the story is given a different turn, the general outline being as follows [**11**]: In the year 1110 B. C., ambassadors from the country now known as Tonquin arrived at the Chinese court with presents for the emperor. As they were in doubt as to the direction of their homeward route, Tcheong-Kung, the emperor's uncle and chief minister, supplied them with five south-pointing chariots, similar to those ascribed to Hoang-Ti. These were to go in advance in order to make known the cardinal points, and thus indicate the way to the party following them. By these means the ambassadors were enabled to find their way "to the seas of Fun-an and Lin-i," and thus reach home. Some commentators add that Tcheong-Kung was the inventor of these south-pointing chariots.

The subsequent history of the contrivance is curious. It is natural to expect that, if it were a genuine application of some magnetic principle, repeated use during several centuries would lead not only to fuller understanding, but also to a wider application. This, however, we do not find. On several occasions between 200 and 1300 A. D. attempts were made to reconstruct the device, but these were only partially successful, and it is plainly stated that at certain times the art was lost or unknown [**12**]. The last version of the tradition throws some further light on this very obscure question, and possibly indicates the real character of the contrivance. "Under the reign of the emperor Jin-tsoung (1027 A. D.) Lou-tao-loung, one of the great officers of the palace, constructed a *ki-li-kiu* or chariot with a drum indicating the *li*. This chariot had . . . two floors, in each of which was a wooden man who held straight a wooden mallet. Directly the chariot had traveled one *li*, the wooden man on the lower floor struck a blow on a drum, and a wheel placed half its height turned once. After the chariot had traveled ten *li*, the wooden man on the upper floor gave a blow on a hand bell" [**13**].

A description, accompanied by a figure, of the south-pointing chariot is given in a Chinese cyclopedia [**14**] published in 1309, and this has been reproduced by Klaproth [**15**]. The description is not sufficiently clear to enable us to understand the construction or the mechanism. But it states that when the monastery of You-mon-ngan was built in 1314-20 A. D., the chariot was used to fix the alignment of the walls.

References to the south-pointing chariot occur in Japanese literature after the middle of the seventh century A. D., but no details as to their construction are given [**16**].

4—We have now to consider the extent, if any, to which reliance can be placed on this Chinese claim to priority, in so far as it is based on the south-pointing chariot. Since the story goes back, or has been carried back, to the 27th century B. C., we are at once confronted with the general question of the accuracy of Chinese chronology. This is founded on cycles of sixty years, which may be extended backwards indefinitely. But to place real events in their appropriate period is another matter, and there is absolutely no guarantee that this has been done on the basis of actual historical record. The question is too wide and too complicated for treatment here, nor is the present writer qualified to be its exponent. But perhaps it may be sufficient to state that the general consensus of opinion among those who have studied the matter seems to be that no reliance can be placed on any Chinese chronology earlier than 800 B. C. [**17**]. Again, the actual history of the documents upon which later historians have built up the Chinese annals is imperfectly known, nor has the extent of their freedom from alteration or interpolation been fully determined [**18**]. Lastly, the story of Hoang-Ti has all the *indicia* of myth, and cannot be accepted as an actual historical occurrence.

These are preliminary objections, and they might perhaps be regarded as sufficient to dispose of the matter, but the south-pointing chariot has been put forward so persistently as the basis of the Chinese claim that more detailed examination is necessary. Effective criticism must be directed to the literary history of the story, and also to the device itself. As regards the former, Legge has shown [**19**] that there is no authoritative mention of it before the second century A. D.; and others have proved [**20**] that the passage in the memoirs of the Chinese historian Se-ma-Tsien, in which the Tonquin embassy is referred to, is an interpolation. Lastly, the story did not pass without question in China itself, for we read [**21**] that Kao-tang-lung and Chin-lang, two scholars of the third century A. D., appeared before the Chinese court and argued that there never had been any such thing as a south-pointing chariot, and that the story was a fabrication.

As for the device itself, we know practically nothing of its details. In any case, there is no reference in any of the older accounts to any magnetic principle involved in its construction, although some of these accounts were written after a knowledge of the attractive power of the lodestone was more or less common property. Nor, apart from the name [**22**], is there any term used in its description which indicates a knowledge of any magnetic principle. It is true that these contrivances came to be known as "magnetic chariots," but this arose through the error of the Jesuit missionary Gaubil. Misled by the similarity between the Chinese name for the south-pointing chariot and that for the com-

pass, he concluded [23] that both were applications of the same principle. But there is no evidence whatever that steel magnets were known either in the 27th or in the 12th century B. C., and it is exceedingly doubtful whether any piece of lodestone could be obtained of magnetic moment sufficient to actuate any mechanism such as the figure on the south-pointing chariot.

With regard to other possibilities, there is distinct evidence [24] that one, at least, of the purposes of these chariots was the measurement of distance along a road or track, and there is much to support the belief that this was their only function. Indeed, Giles [25], supported by Hopkinson, was strongly of opinion that they were merely mechanical contrivances, and this is also the conclusion reached more recently by Hashimoto, Mikami, and Moule [26]. The fact, or the statement, that the art of constructing them was lost more than once points in the same direction, for this might happen with a clever mechanical device of which no plan or other copy existed, but not with a simple matter such as the directive property of a magnet. Once this was known, the knowledge would not be easily lost. Nor can it be said that these chariots were in real or common use for practical purposes. More than one of the early accounts [27] seem to regard them as ornaments for use on ceremonial occasions, and even then only by the highest dignitaries.

It is of importance to note that although the south-pointing chariot is referred to in Chinese literature down to a date long after a knowledge of the properties of a magnet had become, or are supposed to have become, common, yet there is no reference in that literature to the magnet in association with the south-pointing chariot, as would have been the case if a magnet had been the directing agent.

It may also be well to state the best that can be said for the case as also the worst that can be said against it. The former may be founded on a hint conveyed in one of the commentaries [28] of the fifth century A. D., which states that in order to make the contrivance work properly a man had to be stationed inside the box on which the figure was placed. If it be assumed that at this period the Chinese were acquainted with the directive property of the magnet, it is conceivable that the man might cause the arm of the wooden figure to follow the indications of some primitive form of compass also enclosed within the box. But this is mere conjecture, and beyond the hint referred to, there is nothing that can be quoted in its support. As for the latter, it cannot escape notice that much of the attention given in Chinese literature to the story comes after the "Burning of the Books" in 213 A. D. Doubtless, extraordinary efforts were made after this event to reconstruct the Chinese annals, and abundant opportunity would be offered for the interpolation of unauthorized matter. It is possible that the legend had its beginning in these circumstances. The fact of its being contradicted in the third century, as noted above, suggests this solution, and this view is supported in recent times by a Chinese writer [29]. Lastly, there is force in the contention of Giles, that the Chinese themselves have never claimed priority in the invention of the compass, and that it has been forced upon them by foreigners who have misinterpreted their chronicles.

The Chinese claim to priority, advanced on the story of the south-

pointing chariot, has had its defenders [**30**], but is now generally rejected. For the reasons given above, this rejection appears to be fully justified.

5—We have now to summarize the references to the compass as they occur in Chinese literature of historic times, in order to adjudge the claim, based thereon, for Chinese priority in the knowledge of the directive property and its applications.

There is evidence, slight but perhaps sufficient, to prove that the Chinese, like most nations, have known the attractive power of the lodestone from very early times [**31**]. But the date at which the further knowledge was reached that the lodestone can magnetize iron or steel is still uncertain. As for the directive property, it is usual among writers on the subject to quote as earliest mention of this fact the dictionary *Choue-wen*, compiled in 121 A. D. The word "magnet" or lodestone is here given as "the name of a stone with which we give direction to the needle," and this definition [**32**] is copied by later Chinese lexicographers [**33**]. The interpretation of this isolated passage is doubtful, for it may have one of two meanings. First, that after contact with lodestone a suitably mounted needle shows the directive property. Second, that such a needle assumes a particular direction when under the temporary influence of a piece of lodestone placed near it. The first involves a knowledge of the process of magnetization and of the directive property of the magnetized body; the second is but a slight advance on the knowledge of the simple attractive property of the lodestone. The absence of any reference to the north-south direction of the needle suggests that the second interpretation is to be preferred. The passage cannot, therefore, be accepted as proof, either presumptive or final, that the Chinese were acquainted with the directive property in 121 A. D., and we must look elsewhere for evidence. This, we are told by several writers [**34**] is to be found in the dictionary *Poei-wen-yun-fou*, which states that under the Tsin dynasty (265-419 A. D.) there were "ships pointing to the south," to which some commentators have quite unwarrantably added "by the magnet" [**35**]. The interpretation here is again doubtful, and it would be unwise to place reliance on the passage. Gaubil [**36**] stated that he had found, in a Chinese work of 220 A. D., a reference to the use of the compass to mark the cardinal points, but this book has never been seen by others and is certainly now unknown. To this may be added the fact that Gaubil and Amiot confused the south-pointing chariot and the compass.

So far, then, it may be stated with tolerable certainty that there is no clear and reliable evidence that the Chinese were acquainted with the directive property of the magnet before 400 A. D.

From this date there is a gap of seven hundred years in which, with one exception, to be mentioned presently, there is no known reference to the magnetic needle or compass in Chinese literature. This is a somewhat remarkable fact, and it forms a strong argument against the Chinese claim to priority in so far as that claim is based on the references already given. The exception referred to is also doubtful. Wylie stated [**37**] that in the life of the Buddhist astronomer Yih-hing, who lived about 700 A. D., it is said that "on comparing the needle with the north pole he found the former pointed between the constellations *hu* and *wei*," and in a direction nearly three degrees east of the north pole. But Wylie gave no exact reference which would allow of this passage

being identified, and although searched for by others [**38**], it has never been found. Its similarity to passages in other and later Chinese works raises the suspicion of interpolation. We have therefore to pass on to the period 1030-1093 A. D., the lifetime of the encyclopedist Shon-kua, who wrote the *Mung-khi-py-than*. He says [**39**] that "fortune tellers rub the point of a needle with the stone of the magnet in order to make it properly indicate the south." This was repeated by Keou-tsoung-chy in his medical and zoological treatise entitled *Pen-tsao-yan-i* [**40**], which was compiled between 1111 and 1117, from which again it was copied into another work of the same class entitled *Pen-tsao-kang-muh* [**41**]. It also appears in the twelfth century dictionary *Poei-wen-yun-fou* [**42**].

It may be convenient to pause here in order to consider the circumstances in which the statement of Shon-kua was published and repeated. If, as has been argued by several writers, the Chinese knew the properties of a magnetized needle about the beginning of the Christian era, why should an encyclopedist writing ten centuries afterwards take the trouble to refer to a matter of such common and long-acquired knowledge? On the other hand, the fact of his mentioning it indicates that it was knowledge recently acquired, especially when we remember that for several centuries previously no statement on the subject is found in Chinese literature. Further, the fact that it was copied into other Chinese works soon after its publication supports the view that Shon-kua's was an original statement. For these reasons it is safe to hold that this is the earliest reliable evidence of Chinese knowledge of the directive property of the magnet.

The application of this property by the Chinese to the construction of a compass is the next point for consideration. Klaproth [**43**] argued that the Chinese sailors who voyaged from Canton to India in the seventh and eighth centuries must have required the magnetic needle to guide them. To this, there are several weighty objections. The earliest known individual traveler in Eastern seas was the Buddhist pilgrim Fahien, who returned to China from India in the early part of the fifth century. He speaks [**44**] of the difficulty of finding direction at sea: "there is no means of knowing east or west; only by observing the Sun, moon, and stars was it possible to go forward"; and he does not refer to any compass. Renaudot [**45**] has shown from the record of voyages made by two Mohammedans to China in the ninth century that in all probability their navigation was from point to point along the coast, and the compass is not mentioned. Later researches into the records of other early voyagers fully confirm this conclusion [**46**]. Lastly, there is no positive evidence of the use of the compass *by the Chinese* either at this period to which Klaproth alludes or at any later time before the thirteenth century. It must be added that for the widespread belief that the Chinese were the first to use the compass for navigation, Humboldt is to be held responsible [**47**]. In his hands, the cautiously expressed inferences of Klaproth became actual historical occurrences. In the present instance he states in a quite unqualified manner that these early voyagers did actually use a compass. For this there was no warrant whatsoever.

The earliest mention of the use of the compass in China, though not by the Chinese, is that quoted by Hirth in the following passage, the importance of which requires that it should be quoted at length

[**48**]: "It occurs in a work of the twelfth century entitled *Ping-chou-ko-than*, and compiled by one Chu-yu, a native of Hu-chou in Cho-kiang. In the second chapter of this work the author has inserted a series of notes on the foreign trade at Canton which, previous to the arrival of the Portuguese in Eastern waters, had been in the hands of Arab and Persian navigators. Since, from what we know of the author's lifetime, he himself never lived at Canton, whereas his father, Chu-Fu, had held office there at the end of the eleventh century, the critics of the great catalogue of the Imperial Library (*Tsung-mu*, ch. CXLI, 15) hold that his information about the foreign trade in Canton is based on accounts of Chu, the father, and that it therefore dates from the latter part of the eleventh century A. D. This view is supported by the fact that the years 1086 and 1099 are mentioned in Chu-yu's paragraphs referring to Canton in other connections. Among these interesting notes I find one (ch. II, p. 2) referring to the foreign ships by which trade was carried on between Canton and San-fo-tsi (Palembang) on the coast of Sumatra, and further on to ports in Arabian countries, including India. It runs as follows: 'In clear weather the captain ascertains the ship's position at night by looking at the stars, in the daytime by looking at the Sun; in dark weather he looks at the south-pointing needle (*chi-nan-chou*)'."

The next piece of evidence is from the *Chu-fan-chi* of Chau Ju-kua, which has been assigned to the middle of the thirteenth century. It refers to "the boundless ocean where . . . the ships sail only by means of the south-pointing needle, if it be watched by day and night, for life or death depends on the slightest fraction of error" [**49**]. Another item of relevant evidence is that of Tcheon-tha-khoun. About the end of the thirteenth century he visited Cambodia, and in his *Tchin-la-fung-thou-ki* [**50**], describing the country and its usages, he gives sailing directions in terms of compass-bearings. Nothing is stated as to the nationality of the vessel in which he sailed. The last point is that Chinese ships must have been fully acquainted with the use of the compass by about 1400, for Fei-Hsin, the author of an account of four voyages in the Indian Ocean in the early part of the fifteenth century [**51**] quotes a Chinese sailors' song [**52**] which alludes to the compass.

The trend of the evidence thus summarized is towards two conclusions. First, that the Chinese knew of the directive property of the magnet by the eleventh century, and probably late in that century. Second, that the application of this property to the compass, in some primitive form, had been made by the end of the eleventh century, but this was then done, not by the Chinese, but by Arab or Persian navigators. But it must be carefully noted that the date in this latter conclusion depends not only upon a single document, but on a particular interpretation of that document.

The earliest form of the Chinese compass was that of a magnetized needle attached to a straw, or piece of wood or pith, which floated in a basin of water. This continued in use in China [**53**] and Korea [**54**] until the seventeenth century. The pivoted needle does not seem to have been generally used in China before the seventeenth century [**55**], and thus improvements were only effected after commercial relations with the outside world were fully established. It has been argued [**56**] that the form of the more recent Chinese compasses, with their shorter

needles [**57**], and division into twenty-four [**58**] instead of thirty-two points [**59**] is indicative of their independent and possibly earlier origin. But on the supposition of its being an imported invention, the compass might have first reached China in a very primitive form, and been there adapted to existing customs. Among these, the customary division of the circle into twelve or twenty-four parts would determine the form of the instrument. It was also suggested by Barrow [**60**], in view of the astrological and other symbols on many Chinese compasses, even of recent times, that the Chinese would never have condescended to use a foreign instrument for such purposes, and therefore that the compass must have had a Chinese origin. The obvious answer is that the earliest form of the Chinese magnetic needle was used, not for navigation, but by necromancers for purposes of divination, and that its development took place along these lines rather than the technical application it has found among other nations [**61**].

Two other comments on Chinese knowledge of terrestrial magnetism may be made in closing this section of the subject. The first is to point out, after Martin [**62**], that in no Chinese writing, ancient or modern, is there any allusion to magnetic repulsion. If this silence is to be used as a measure of their knowledge of the subject, it would mean that they have been far behind the Western nations. The second is that, if it be true that a knowledge of the directive property of the magnet and its application to the compass had been reached by the Chinese in the eleventh century, not to mention earlier assignments, it is more than strange that several hundred years should elapse before any reference to such matters is found in Japanese literature. The earliest record of the kind there, according to Hashimoto [**63**], does not occur until the middle of the Tokugawa period, 1603-1867.

Before attempting any general conclusions from the evidence which has now been summarized, it is necessary that we should deal with similar claims from other countries or races, and to this we next proceed.

6—In the historical order of the person concerned, the next [**64**] claim is that which ascribed a knowledge of the compass to Solomon, King of Israel. This was put forward by Goropius [**65**], Pineda [**66**], Fuller [**67**], and others [**68**]. In more recent times it was again advanced by Clarke [**69**]. Each of these writers had his own ground for the supposition, but the arguments employed cannot be taken very seriously. It was urged that the *Parvaim* of the Bible [**70**] is Peru, navigation to which would require a compass; that Tarshish [**71**] was the Spanish Tartessus, voyages to which were quite frequently undertaken by the Tyrian navigators, who were probably acquainted with the compass; or that the voyage to Ophir [**72**], wherever it might be, meant navigation over the open seas, thus again necessitating a knowledge of the instrument; or, lastly, on the general ground of the great wisdom of Solomon, presumably assisted by the practical experience of the "servants who have knowledge of the sea" [**73**]. But there is nothing in the Biblical references [**74**] to suggest more than the highly probable conclusion that, ten centuries before our era, navigation must have been a tedious and difficult business, and thus no real matter is provided which bears on the present issue. For contemporaneous criticism, reference may be made to Hakewill [**75**], Acosta [**76**], Kippingius [**77**], Bochart [**78**], and to the curious comment in *Purchas, His Pilgrims* [**79**].

7—The literature of classical antiquity contains many references to the attractive quality of the lodestone, but it is now certain that it reveals no knowledge of the polarity of the magnet, or of its directive property in the Earth's field. In every case in which a claim of the kind has been made, it can be shown that the interpretation put upon the passage is a forced one. The arrow which enabled Abaris to travel wherever he pleased was supposed by Salverte [**80**] to be a magnetic needle. Cooke [**81**] suggested that the cup given by Apollo (or Nereus or Oceanus) to Hercules by which he sailed the ocean might have been a compass. He also interpreted Homer's reference to the maritime skill of the Phaeacians as meaning that a compass was in use during the siege of Troy [**82**], and this was repeated by Buffon [**83**] and Mottelay [**84**]. But his rendering of the passage is widely different from that of modern scholars. A similar ingenuity has invoked the image of Jupiter Ammon, the Golden Fleece, and the ship Argo. Falconet [**85**] believed he had found, in one of the fragments of Euripedes preserved by Suidas, evidence that the author knew of the repulsion of opposite poles of a magnet, but ultimately decided against this conclusion. Professor D'Arcy Thompson [**86**] is of opinion that the "magnes" to which Euripedes refers is not the lodestone, but some substance having the false appearance of silver, and this agrees with the views expressed by Martin [**87**] and Buttmann [**88**]. Aristotle was credited by Albertus Magnus [**89**] and Vincent of Beauvais [**90**] with a knowledge of the directive property. These authors quoted from a tract, *De Lapidibus* [**91**], which some Arabic writer had represented as a work of Aristotle. This tract, which they admit they never saw, is now lost, but there are sound reasons for regarding it as a spurious production. The suggestion was made by several writers, among whom Levinius Lemnius was probably the first [**92**], that the word *versoriam* as used by Plautus [**93**] meant a compass. But in reality this was an afterthought inspired by Gilbert's invention [**94**] of the word *versorium*, and its subsequent introduction into the literature of the subject by Cabaeus [**95**]. The term used by Plautus probably means either the rudder of a ship or the rope fastened to the lower and leeward corner of a sail [**96**]. Sir Roger Lestrange took an unusual and quite unwarranted liberty in his translation [**97**] of Seneca's *Morals*, when he represented the seamen of classical times as having a knowledge of the compass. He did not, however, go as far as did Poinsinet de Sivry [**98**], who said that the ancients had a mechanical compass which contained no magnet. There are vague references in Plutarch [**99**] to repulsion between opposite poles of two magnets, but their significance is extremely doubtful. According to Betham [**100**] the Etruscans were acquainted with the compass, and this is founded on an inscription on an Etruscan tomb, accompanying the design of an eight-rayed star with the fleur-de-lis on one of the rays. The inscription was said to refer to "steering over the ocean by night or day," but this has been differently interpreted by the Italian archaeologists [**101**]. Practically the only direct evidence we have from classical writers which bears on the subject consists of two passages from Virgil and another from Ovid, and these clearly indicate that in classical times navigation was by means of the stars [**102**].

With regard to these supposed allusions to the directive property of the magnet, they are condemned by the silence of classical antiquity

generally. Bertelli [**103**.f.] examined the writings of more than seventy Greek and Latin authors between 600 B. C. and 1000 A. D., but none of them yielded any evidence of knowledge of this property. Acosta [**104**], Dutens [**105**], and Azuni [**106**], though after less exhaustive search, came to the same conclusion, and although Gibbon had said that Greek can give "a soul to the objects of sense and a body to the abstractions of philosophy," Azuni added that neither Greeks nor Latins had any word to express the idea of polarity. It is practically certain that if the directive property of the magnet had been known in the Roman Empire before 400 A. D., it would not have escaped comment in the *Magnes* of the poet Claudius [**107**]. But he is silent on the point. Nor is it likely that St. Augustine, in speaking at length [**108**] on the attractive properties of the magnet, would have omitted reference to its polar and directive properties if they had been known when he wrote his famous book, 413-426 A. D. The nearest approach is to be found in a passage of Marcellus Empiricus, who was physician to Theodosius the Great, and lived at the end of the fourth century. He speaks [**109**] of the magnet or lodestone repelling as well as attracting iron, and it is probable that he had been experimenting with pieces of magnetized iron or steel.

8—The Phenicians have frequently been credited with knowledge of some form of compass, chiefly on the general ground that their extensive voyages required such aid [**110**]. Had the annals of Tyre and Sidon been preserved to us, the question might have been answered definitely; as it is, nothing is known which points to any such conclusion. All we do know with regard to the navigation of the Phenicians indicates that they determined direction at sea by astronomical means. While the Greeks continued to use the constellation Ursa Major for this purpose, the Phenicians had found that the Cynosure in Ursa Minor was much nearer the pole of the celestial sphere, and this gave them their true north [**111**]. On this account, the pole star was known in antiquity as the Phenician star [**112**]. The most ancient Phenician book, written by, or ascribed to, Sanconiathan [**113**] is now believed to be a forgery by Philo of Byblus. But it contains a reference to "betulae," or "stones which moved as having life," which has been interpreted by some commentators as meaning the lodestone. Even if it did have this meaning, it does not follow that a knowledge of the directive property had also been reached. Betham [**114**] took it as proof that the Phenicians were acquainted with the compass, but no evidence is forthcoming in support of this conclusion. Fuller [**115**] ascribed the magnet, known in early times as *lapis Heracleus*, to a Phenician navigator named Hercules, but gives no ground for his assertion, which is probably based on a passage in Photius [**116**]. Gilbert [**117**] concluded that the Phenicians could not have been acquainted with the use of the lodestone or magnet in navigation, otherwise the Greeks and Romans would have acquired the knowledge. But this is to prove too much, for it is known [**118**] that the Phenicians took extraordinary precautions to preserve all secrets connected with their trade and navigation. "To a Phenician commander, mystery was the great principle of his profession." The story told by Herodotus [**119**] of the circumnavigation of Africa by the Phenicians shows that they deduced the direction of a coast line by reference to the rising Sun [**120**]. A curious sequel to this story—based on the supposition of Osorius [**121**] that the compass was

brought to Europe by Vasco da Gama, who found it in use by the pirates about the Cape of Good Hope—was provided by Cooke [**122**], who made the rather wild proposal that these pirates were the lineal descendants of the Phenicians referred to by Herodotus.

It may be convenient to refer here to arguments which have occasionally been put forward [**123**] to show that the ancient Egyptians were acquainted with the directive property of the magnet, and that the orientation of the base of the Pyramid was accomplished by an application of that knowledge. But the fact is that the sides of the base of the Pyramid are directed north-south and east-west geographically, with a degree of accuracy unattainable by magnetic observations; and these directions being geographical and not magnetic, would also imply a knowledge of the declination. For this there is not the slightest ground. It has also been suggested that the names given by the Egyptians to certain kinds of iron can be best explained by supposing that they meant magnetized iron which pointed north and south. But there is nothing which can be quoted in support of this conjecture [**124**].

9—In recent years, the most general opinion with regard to the origin of the compass has been that a knowledge of the directive property of the magnet was obtained from the Chinese by the Arabs, and applied by the latter to the construction of some primitive form of compass, which was subsequently introduced by them to Europe, probably about the time of the Crusades [**125**]. This is, perhaps, the most difficult part of the whole question. The direct evidence is scanty, and its implications are frequently ambiguous. Of the writers who have propounded or repeated this conclusion, none has explained how, in the conditions prevailing before and during the Crusades, this transmission of valuable knowledge was actually effected. It has been given, and left, in the form of a conjecture, plausible yet unsupported. Whatever decision be reached, a certain weight has to be given to the dangerous argument—of varying value in different ages—that silence on a given subject implies ignorance regarding it. Reliance has also to be placed on considerations drawn from spheres of human thought and activity having only remote connection with our particular problem.

The wholly negative evidence available with regard to the use of the compass in eastern seas, down to 1000 A. D., may first be considered. The earliest known statement of the kind is that of Ptolemy [**126**], who wrote in the middle of the second century A. D., and said that navigation in the Indian seas was carried on by means of the star Canopus. The next record is that already quoted from the travels of Fahien, the Chinese pilgrim who made a journey to India overland and returned by sea during the fifth century. He sailed from the Hooghly to Ceylon, thence to Java, and on to Tsingtau. From what has been stated already [**127**], it is quite clear that any position or direction finding was by astronomical means, and there is no mention of guidance by the magnetic needle. No evidence is forthcoming as to the nationality of the vessel in which he sailed from Ceylon to China, but in all probability, as far as Java at least, it might be an Arab ship; less probably Indian. In their edition of the work of Chau Ju-kua, Hirth and Rockhill state [**128**] that Fahien's description of navigational methods was correct not only for the fifth century in which it was written, but even down to the twelfth century; that when pilots went out of sight of land,

they trusted to the regularity of the monsoons, steered by the Sun, moon, and stars, and took frequent soundings. Next, we have the records collected by Chavannes [**129**], Pelliot [**130**], and Ferrand [**131**] of voyages undertaken by Buddhist pilgrims and others, and by Levi [**132**] on the travels of Vajrabodi in the eighth century. These contain several references to navigation in the Indian and Indo-Chinese seas, but there is no mention of the magnetic needle or compass. Some, if not most, of these voyages would be in Arab ships. Another device of the times was the use of birds which, when released from a ship at sea, would seek the land if near or return to the ship—a method as old as the story of the Deluge, and reappearing at intervals down to the times of the Icelandic sagas [**133**]. Renaudot's account of the voyage of two Mohammedans from the Persian Gulf to China in the ninth century [**134**], has already been referred to as confirming the negative results of the foregoing evidence [**135**].

From the actual practice of navigation in eastern seas, we may turn to Arabic or Persian writings generally, in order to ascertain whether, before 1000 A. D., there is any reference to the use of the magnet at sea. It must be remembered, however, that sea-faring communities among the Arabs would form a class apart, holding little intercourse with those who wield the pen, and we have to wait until the fifteenth century before any Arab or Mohammedan navigator commits his ideas to writing. On the other hand, it must not be forgotten that the Arabs encouraged the study of astronomy and geography to a quite unusual extent, and, later on, that much of the speculative science of the earlier Renaissance period reached the western world through the Arabic schools of Spain. This is a source whose systematic exploration has only been undertaken in comparatively recent times [**136**], and the end is not yet. Thus we have a very considerable volume of Arabic writings dealing with cosmographic subjects, and these have to be examined for our present purpose. The Koran declared [**137**] that "He hath given you the stars to be your guides in the dark, both by land and sea," which indicates the methods used by navigators in the seventh century. After this, the next record is the manuscript of Thabet-ben-Corah [**138**], from which it may be gathered that towards the end of the ninth century the compass was not known to the western Arabs. Ibn-Al-Adari, an Arabic writer of Morocco, who lived in the fourteenth century, wrote a history of the Western nations [**139**] in which he refers to a battle in the year 854 during which a certain Qasim was killed. On this defeat, Qasim's brother, Safwan, wrote a verse in which the word *qaramit* occurs. Dozy, who translated the original, held that *qaramit* means *calamita*, one of the ancient names for lodestone. But the reading is doubtful, and if the word has this equivalent the verse is devoid of meaning. In any case, it reveals no knowledge of the directive property. The Arabic geographer, Ibn Khordadbeh, who died in 912, had excellent opportunities in his official capacity as "Postmaster General" under Motamed, the Baghdad Caliph, for ascertaining the details of navigational practice. He wrote [**140**] on the attractive properties of the lodestone, but has nothing to say as to its directive property. A similar negative result follows from an examination of the writings of other Arabic cosmographers before 1000 A. D., such as Mohammed (the Kharizmian) [**141**], Amron Aljahedh [**142**], Al-kindi [**143**], Abeladory [**144**], Abulfara-

gius [**145**], Ibn Muhalhil [**146**], and especially Masoudi [**147**] and Geber [**148**]. The general conclusion from all these sources is that there is no evidence for Arabs, Persians, or Mohammedans generally having any knowledge of the directive property of the magnet, or of its application to navigation, before 1000 A. D.

The next step is to ascertain the general course of sea communication between east and west before and during the Crusades, the object being to obtain some idea of the conditions affecting the extent or frequency of contact between Chinese and Arabs and between Arabs and Europeans. The trade-routes, as far as these lay by sea, were (1) by the Red Sea, southern coast of Arabia, down the Malabar Coast, across or round the Bay of Bengal, through the Straits of Malacca, and on to China; (2) by the Persian Gulf to the Malabar Coast, and onwards by the first route. In dealing with these, it is more convenient to begin at the eastern end of the line, and with the Chinese. There is sufficient evidence [**149**] to show that, long before the period, 1000 to 1250 A. D., now dealt with, Chinese ships sailed to Java, Ceylon, and the Malabar Coast, although the trade to the west of the Malacca Straits suffered a check on more than one occasion, owing to the changing policy of their government [**150**]. They are reported as trading to India in the seventh century, and as being established at Quilon in 953 [**151**]. Their agencies were maintained on the Malabar Coast down to the fourteenth century [**152**], after which they seem to have been driven off for reasons or by means which are not clearly apparent. As regards extension westwards, it is more than doubtful whether they reached Aden, and their visits to Madagascar, relied on by Humboldt [**153**], are entirely apocryphal. As to the Red Sea, it is certain that they never entered it. Navigation there was difficult, and was entirely in the hands of sailors acquainted with local dangers. With regard to the Persian Gulf, Masoudi states [**154**] that Chinese ships traded to Siraf, then the port of Farsistan [**155**]. But this does not seem to have been the usual practice, for they are generally heard of as waiting in the Malabar ports for the change of monsoon to take them homewards [**156**].

In these eastern waters the Arabs were active from very early times. Originally the Red Sea trade was in the hands of the Greek sovereigns of Egypt, and afterwards passed under the Roman domination [**157**]. By the time of Strabo, who died in 25 A. D., the Romans had extended their part in the trade as far as India, but not further than the Indus, for Pliny says [**158**] that the Malabar ports were only beginning to be known in his day. This extension would tend to force Arab or Persian maritime activity farther eastward, and there are indications [**159**] that, even in these early times, there must have been trade between India and the Malacca Straits and, possibly, China. But at what stage this was fully established is unknown, nor is it quite clear by what country it was prosecuted. However, we learn that during the sixth, seventh, and eighth centuries Ceylon was an open market for Chinaman, Malay, and Arab [**160**]. Later, Arab trade extended eastwards to China and possibly to Korea, and was firmly established there, for Renaudot's two Mohammedans found populous colonies of their countrymen or coreligionists in China in the ninth century [**161**]. After the disturbed conditions of 878 A. D., China seems to have excluded the foreigner for a time, and Arab ships going east-

wards made Kalah, in the Malacca Straits, their terminal port. It is significant that this brought many Chinese traders to Kalah, showing that the Chinese ships must have been partially or wholly excluded from the Indian trade [**162**]. Westwards, the Arab ships went to Aden, and also up the Persian Gulf. At Aden, goods were transhipped into smaller local vessels and carried to Berenice or other port in Egypt, thence by land or river to Alexandria [**163**]. From the Persian Gulf ports, chiefly Busrah [**164**], trade followed the land or river routes to Persia, Baghdad, and possibly Damascus.

Before leaving this part of the subject it should be noted that there is still some difference of opinion as to the extent to which the Persians took part in this eastern trade. Rawlinson [**165**] was of opinion that the Persians were only freshwater sailors. Quatremere [**166**] held the same view; and Malcolm [**167**] suggested that the sailors referred to as Persians were really Arabs. Later opinion, as expressed by Ferrand [**168**] and Hasan [**169**] would make them out to have been as capable and enterprising as the Arabs. For present purposes, the point is of minor importance. There is also a similar question as to Indian participation in the trade. But the weight of evidence [**170**] is to show that maritime enterprise among natives of the west coast of India chiefly took the form of piracy. Indeed, one writer stated [**171**] that no Indian ships entered the Persian Gulf except for piratical purposes, and Alberuni [**172**], who wrote in 1030, refers to the activity of the pirates of Cutch and Somnath. Jordanus [**173**], who visited the Malabar coast about 1325, speaks with contempt of Indians as sailors. On the other hand, Wilson [**174**] was of opinion that many of the ships sailing in the East at the time of Fahien were Indian.

From the foregoing sketch—it cannot, in the circumstances, pretend to be more—it may be gathered that from the sixth century onwards there was considerable intercourse between the Chinese and the Cingalese, Arabs, Persians, and Mohammedans generally, and that with occasional intermission this continued down to the fourteenth century. That there was therefore opportunity for the transmission between these peoples of knowledge relating to methods in navigation seems quite well established.

The important point now to be considered is the interposition between East and West, of the Mohammedan Empire. By 1000 A. D., Islam had overrun Arabia, Egypt, Syria, Asia Minor, North Africa, and Spain, and extended from the Persian Gulf to the Straits of Gibraltar. It thus offered a solid obstacle to the unrestricted passage of merchandise, and certainly shut off all relations between the merchants and sailors of the East and those of Europe. There are abundant proofs that while the Mohammedan rulers of Egypt encouraged commerce, they reserved all rights over the transit trade between the Red Sea and Alexandria, and any facilities given to Europeans for trade at the latter port were generally the subject of special treaty [**175**]. Further, the importance of Alexandria as a market in the period before and during the Crusades, and the establishment there, under special regulation, of colonies of European merchants, indicate that the Mohammedan government of Egypt was jealous of European interference in the eastern carrying trade, and that Alexandria was a place of exchange rather than a forwarding agency [**176**]. In the Mediterranean the distribution of mari-

time activity varied in different areas and at different times. Before 900 A. D., Saracen enterprise generally took the form of piracy or of descents upon the European shores in search of plunder, while French and Italian ships were more usually engaged in legitimate trade. While the north and south shores of the Mediterranean were thus at constant war, there were occasional compacts between the Saracen and the Italian, in spite of papal and imperial interdiction against trade with the unbeliever [**177**]. But the growing commercial power of Italy gradually asserted its supremacy. Venice cleared the Adriatic from pirates by the year 1000. The Genoese and Pisans expelled the Arabs from Sardinia by 1015, and, later on, attacked them in their own African ports. Half a century later the Mediterranean was practically free from Saracen piracy [**178**], and the command of the sea, with the monopoly of trade, had passed wholly into the hands of the sailors of Venice, Amalfi, and Genoa. During the period now considered the position therefore was that while Arab navigation was active on the eastern side of Suez and Busrah, and while Venetians and Genoese were in command of the Mediterranean, there was no communication between the two; that is, between the merchants in the two areas who organized maritime enterprise. The Mohammedan control of trade acted as an effective barrier. In these circumstances the transmission of knowledge with regard to navigational practice would be highly improbable. And in the Mediterranean itself we cannot imagine the spectacle of a Saracen pirate holding amicable discussion on the fundamentals of terrestrial magnetism with a Genoese captain in the year of grace 1000.

The next step is to summarize the evidence, positive and negative, with regard to the appearance of the compass among Arabs, Persians, or Mohammedans. The earliest mention by any writer of this class is by Mohammed Al-Awfi, in his collection of Persian anecdotes, written in 1232 [**179**]. He describes a floating compass used to determine direction at sea, and from what is known of the author's lifetime, it is probable that he saw it in use during a voyage near the mouth of the Indus in the year 1220. He refers to the instrument as if it were a novelty. But the value of this statement is discounted by the fact that, as far as is known, his experience of ships and seafaring was very limited. The next reference from Arab sources is the allusion in the Spanish *Leyes de las Partidas* [**180**], written about 1250-1257, which refers to the use of the magnetic needle as a guide to mariners. It seems to point to a well-established practice of this means. It is, however, open to question how far this reference should be used as indicative of Arabic knowledge of the matter. This depends entirely on the author of that particular part of the work. The third source also comes from the Mediterranean, and occurs in a manuscript by Bailak of Kibdjadi [**181**], who is generally, but erroneously, referred to as the earliest Arabic writer on the subject. He describes, in 1282, a floating compass which he saw in use during a voyage from Tripoli, in Syria, to Alexandria, in 1242. But it is to be carefully noted that he said nothing as to the nationality of the vessel in which he sailed. At the time of his voyage the monopoly of the sea-trade in the Levant lay almost wholly in the hands of the Venetians, Genoese, and other Italians, and there is exceedingly small probability that it was an Arab vessel. Besides, Bertelli has remarked [**182**] that most pilots in Arab vessels were European slaves or rene-

gades. Bailak also stated that a similar form of the instrument was employed by those who sailed to India. But it is not clear whether he intended this to refer to 1242, the year of his voyage, or to 1282, when he wrote. It is not given as his own observation, and it has been criticized by Renaudot [**183**] and others. It was confirmed, but only after the lapse of two centuries, by Al-Magrizi [**184**], who lived 1364-1442, and described the hollow piece of iron, shaped like a fish, which was used as a magnetic needle by sailors in the Indian seas.

This, then, is all that is known regarding the knowledge of the compass among Arabs, Persians, or Mohammedans before 1250 A. D. But against the theory that the West derived its knowledge of the matter from the East, there stand two very important facts. The first is that, as will be shown later, the compass was known and used in western Europe by 1187, and as it is not referred to as if it were a novelty, it must have been in use for some considerable time. The second is that although it was known to some Arabs or Persians by 1220, that knowledge was very far from being general. For it is possible to quote from many Arabic writers of the time to show that, although they dealt with such questions, they were not acquainted with either the polarity of the magnet, or its directive property, or its application to navigation. Ibn Youni [**185**], the Arabic astronomer, does not mention any of these properties, although there is one part of his work where this might be reasonably expected if the knowledge had been acquired by his time. Al-Kati [**186**], a contemporary, distinguished between two kinds of iron, apparently steel and soft iron, but does not refer to their magnetic qualities. Alberuni [**187**], who wrote in 1030, refers to methods of determining direction, but makes no mention of the magnetic needle. The *Geography* of Shiref Edrisi [**188**], completed in 1153, makes it quite clear that in these days navigation, at least in the Red Sea, was from point to point along the coast. The pilot, as we might expect from the derivation of the word, sat at the bow of the ship and not at the stern, as he would have done if the compass were used as a guide in steering. But the compass is not mentioned, although Fournier [**189**] quotes several writers who thought they had detected it. Damasqui, who lived 1256-1327, wrote a treatise on cosmography [**190**] in which, although he does not mention the compass or magnetic needle, he refers to three kinds of lodestone: one attracts, another repels, while the third attracts at one side and repels at the other. This is of interest, first, because his statement is a repetition of what, as will be seen later, Alexander Neckam had said in the previous century, and second, because it not only shows the dawning of clearer ideas on the subject of magnetic polarity, but also proves that these ideas were developed earlier in western Europe than among Arab peoples. Aboul Hassan, a Spanish Arab, wrote a treatise [**191**] on the astronomical and other instruments of the Arabs, but does not mention the compass or magnetic needle. Lastly, if it is permissible to quote those writers who were probably influenced by the Arabic schools of Spain, it may be stated that there is no allusion to the directive property in the works of Marbod [**192**], Adelard of Bath [**193**], who traveled extensively in search of information, Gerard of Cremona [**194**], or Bernard Silvester [**195**]. Even down to a comparatively late date, we meet with silence on the subject where information might be expected. Except in one extremely doubtful

passage [**196**], Marco Polo does not refer to the compass, although he gives numerous details regarding his voyages in Eastern seas during the thirteenth century. Gilbert [**197**] gave him the credit of having introduced the compass into Europe from China. But the instrument was known and used in Europe for fully a century before he returned [**198**]. Ibn Batuta [**199**] describes numerous voyages he made in the East during the fourteenth century, but does not mention the compass. Nicolo Conti [**200**], in 1420, sailed the Indian seas in a vessel which, from its description, appears to have been Chinese, but might equally well have been Arab or Malay, and he says expressly that no compass was used on board. Lastly, the map of Fra Mauro [**201**], completed in 1457-59, contains in one of its "Rubricks" the statement that Indian (i. e., Arab) ships do not carry a compass, but were directed by an "astronomer" on board. This is the last statement of the kind, for in 1498 Vasco da Gama found the compass or "Genoese needle" in use by Mohammedan pilots on the east African coast [**202**], and in 1503-04 Varthema [**203**] sailed in a Malay vessel from Borneo to Java, when the pilot, probably a Malay, used a compass. It is significant that in this last case, the instrument was adjusted after the European, and not the Chinese, manner, its chief cardinal point being the north, not the south. It was therefore most probably a European compass.

Another aspect of the subject has still to be considered. In connection with the voyage of Vasco da Gama in 1497-98, he found that the local pilots in the Indian Ocean used a compass in which a plate of magnetized iron took the place of the needle [**204**]. Now it is rather curious that, according to Riccioli [**205**], sailors in the Baltic used a similar contrivance as late as the seventeenth century. Possibly this is the instrument to which Salverte [**206**] referred as having been used by the Finns "for ages unknown," but of which we have very little evidence. Adam of Bremen, for instance, does not refer to it [**207**]. Nevertheless, Benjamin [**208**] has founded upon it an argument which may be summarized as follows: The circumstances attending the appearance of the compass all indicate a radiation from some central point of origin. At the epoch of that appearance, Wisby, in Gothland, was a great center for all seafaring peoples. It is, according to Benjamin, more reasonable to suppose that a knowledge of magnetic polarity and of the directive property existed among the Finns than among other races gathered there, because of the affiliation of the Finns and Mongols (who are presumed to have had anterior knowledge of the matter), and because of the reputation of the Finns for peculiar skill in "sea-sorcery." He goes on to point out that a Finnish compass has been discovered [**209**] which lends support to this view, being of great antiquity, and having its card marked, not with the usual quadrants, but with divisions indicating the azimuth of sunrise and sunset at the two solstices for a latitude of 49° 20′ north, which crosses Asia at the region which was the cradle of primitive civilization, and from which began the wanderings of the great family to which both Finns and Mongols belong. This theory must inevitably suffer on two accounts. First, it presumes that the Mongol races had some positive knowledge which could be transmitted. But it has already been shown that there is no evidence of such knowledge among Mongolian races before the eleventh century, and perhaps not even then. Second, the idea of using the magnetic needle

in navigation or in land journeys did not originate with the Chinese. To these there may be added the consideration that there is no obvious reason for the use of the compass on the land routes over Asia; if the route were unknown or uncertain, the compass would not discover it in the absence of a map. Also the fact that the so-called cradle of primitive civilization has yet to be finally located, and present indications do not point to the area chosen by Benjamin. The theory might therefore be set aside as untenable but for its later development in a somewhat different form by Hennig [**210**], and this has a bearing on the question of Arab influence in the matter. According to Hennig, the knowledge of the compass reached Northern Europe by the routes along which an active trade was carried on by the Normans with the Arab Caliphate several centuries before the Crusades. This, it is supposed, would explain the appearance of the compass in the north of Europe before the south. The hypothesis seeks support in the fact that many hoards of Arab coins have been found in Russia, the Baltic States, Scandinavia, and Germany, their dates extending from 698 to 1010 A. D. [**211**].

This theory is practically the only exception to the rule, already mentioned, that no writer on the subject has attempted any explanation of the means by which the supposed prior knowledge of the Arabs regarding the compass was passed into the western world. It is mainly founded on the facts relating to the trade which Arabs carried on with Bulgarians, Russians, Lithuanians, and Scandinavians in pre-Crusading times. That by these means there might be communication of knowledge on various subjects may be granted, but only with certain restrictions. The first of these is that there is very little evidence that Arabs ever penetrated into Russia farther than the country of the Khazars on the Volga. If there was any extensive interpenetration, it was rather due to the Normans traveling south by the Dnieper. The second is that Moslem trading enterprise had suffered a serious decline before the Crusades, and this before any supposed Arab knowledge of the compass existed. And third, the general consideration that it is improbable that any novelty in the art of navigation would be transmitted by travelers or merchants who were wholly occupied in land journeys over Central Asia or the Nearer East. But the chief objection to the theory is the utter absence of any evidence pointing to an early knowledge of the compass among the Normans. Had it been known to any seafaring people among them, it would be known to the Norwegians and Danes, and of this there is absolutely no proof. As for the earlier appearance of the compass in the north of Europe as compared with the south, this has by no means been established, and it certainly cannot be taken for granted. With regard to the hoards of coins, Heyd [**212**] is inclined to the belief that they may be the loot gathered by Normans who went ravaging southwards in the tenth century. Interesting and ingenious as this theory may be, it does not seem to carry us further towards an explanation.

We may now sum up the evidence bearing on the question of the transmission of the knowledge of the compass by the Arabs from China to Europe. The leading points are as follows. First, the statement of Shonkua, of uncertain date, but before 1093, showing Chinese knowledge of the directive property. Second, the notice, published by Hirth, of the use of the magnetic needle by Arabs trading to Canton about

1100. Third, the mention by Awfi of the use of the compass on the northwest coast of India in 1220. Fourth, the extent to which the Mohammedan empire restricted direct communication, and therefore interchange of ideas, between east and west. Fifth, the appearance of the compass in western Europe certainly before 1187, and in the Levant in 1204. Now, with regard to the first of these, reasons have already been given for holding Shonkua's statement to be the earliest of its kind, and there is no immediately apparent ground on which it can be discredited. But in reference to the second, there must be considerable doubt. It is an isolated statement, is confirmed by no contemporary writer, and depends for its value upon the date assigned to it by the Chinese scholars of the Imperial Library. That value is seriously discounted by the fact that for more than 120 years thereafter we hear no more of the compass in use by Arabs or Persians. It is quite possible that further critical examination of Chu-Yu's *Ping-Chou-ko-than* may confirm Hirth's conclusions. Meanwhile, it is proposed that it be held in suspense until this has been done.

Hence the conclusion reached on the matter is, that the Chinese were acquainted with the directive property of the magnet by 1100 A. D.; that they did not then employ it in navigation; that there were serious obstacles to the transmission of this knowledge from east to west; that the compass was in use in western Europe by 1187, and considering the time which must have elapsed between the discovery of the directive property and the application to the construction of a primitive compass, it is most probable that its origin in Europe was independent of, and possibly as early as, if not earlier than, that in China. The appearance of the compass in the Levant in 1204 probably derives from its western European origin. Where Awfi's compass of 1220 came from, we do not know; east or west are both possible, and the latter the more probable.

10—We have now to examine the literature of Europe from medieval times onwards, in order to collect the known or supposed references to the directive property of the magnet and to the compass. First of all, it may be well to clear away as far as possible any matter of a doubtful kind and to mention one or two points of negative evidence.

The earliest of several doubtful claims to priority is that put forward on behalf of Salamone Ireneo Pacifico, of Verona, who lived 778-846. This was first suggested by Posteraro [**213**], and was based on an inscription on the tomb of Pacifico in the cathedral of Verona. But Bertelli [**214**] has shown that Posteraro's interpretation of the inscription is erroneous.

The second is connected with the monk Gerbert, who, in 999, became Pope under the name of Sylvester II. There seems no doubt that he was one of the most learned men of his time. The Benedictine authors [**215**], in giving an account of his life, quote a passage from Ditmart [**216**], which has been taken by some to mean a telescope, and by others to refer to some form of compass. From Gerbert's own letter to the monk Constantine, Ameilhon [**217**] has shown that it can refer to neither, and the point has been discussed with similar results by Trombelli [**218**], Montucla [**219**], and Baldelli Boni [**220**].

The third is a passage, quoted by Gibbon [**221**] from the historical poem of Gulielmus Appulus as supporting the idea, widely prevalent

in Gibbon's time, that the compass was discovered by the sailors of Amalfi. This poem shows internal evidence of having been composed between 1088 and 1111, and the passage in question must have been completed after July, 1099. But it might equally well apply to navigation by the stars, and makes no explicit reference to the compass.

The fourth is that brought forward by Hansteen [**222**], according to which the Norwegian historian Ara Frode, born 1068, asserted in his *Islands Landnamabok* [**223**] that the lodestone was not used in navigation in the year 868, when Vilgerderson set out to discover Iceland; the presumption being that it was known and used by the time at which Frode wrote. But Kamtz [**224**] showed that the passage quoted by Hansteen is of much later date than the time of Frode, and that the work attributed to him was really the production of several later writers down to Haukr Erlandson, who died in 1334. Kamtz also stated that three different manuscripts of the *Landnamabok* do not contain the passage relied on by Hansteen, and this has been confirmed by Klaproth [**225**]. It may be mentioned here that the Danes made some remarkable voyages before the end of the thirteenth century. But according to the Sagas, they did not use the compass. They calculated distance by a day's sail of 27 to 30 miles, and guessed at the direction of the nearest land by the flight of birds [**226**].

The last of these doubtful allusions is that which is ascribed to William the Clerk, also known as William the Norman, and was said to have been discovered by M. Paulin Paris, the distinguished French antiquary. The facts of this case may be summarized as follows: A manuscript, now in the Bibliothèque Nationale, Paris [**227**], contains a poem in which there occurs a reference to the attraction between the magnetic needle and the pole star, and describes a compass consisting of a magnetized needle inserted through a cork which floats on water. The first writer who referred to this poem was Fr. Michel [**228**], shortly before an article by M. Paulin Paris appeared in September, 1836 [**229**]. As stated in this latter article, the manuscript was transcribed in 1329 by Robert (or Robechonnet) de Gonnecourt, and it contains several poems. The fifth of these contains the allusion in question, and because it comes immediately after two others known to be by, or generally ascribed to, William the Clerk, M. Paulin Paris ascribed it to the same author and therefore dated it 1160. He gave no reason beyond this for the ascription to William the Clerk. But there are abundant reasons for doubting this conclusion. To begin with, the reason given is weak. Second, there is no assertion as to the authorship in the poem itself. Third, the passage relied upon bears such a very close resemblance to another in the well-known poem, *La Bible*, of Guyot de Provins, to be mentioned later, that it might well be regarded as having been inspired, if not copied, therefrom. Fourth, as regards the date of its composition, Wright [**230**] is of opinion that it probably belongs to the beginning of the fourteenth century, possibly to the century preceding. This would bring it down to a date fully a century later than that assigned to it by M. Paulin Paris, and certainly later than 1206, when Guyot wrote. In all probability, therefore, it was not written by William the Clerk. For these reasons the poem and the description of the primitive compass which it contains cannot be given the priority sought for, and the claim based upon it must be rejected.

11—We come at last to something of a perfectly definite and well-authenticated kind. Alexander Neckam, monk of St. Albans, who was born in 1157 and died in 1217 [**231**], wrote two treatises, *De Utensilibus* [**232**] and *De Rerum Naturis* [**233**]. The dates of their composition are not known exactly, but may with safety be assigned to the last quarter of the twelfth century, possibly not much later than 1187 [**234**]. In the first he describes the use of the magnetic needle to indicate the north, and states that mariners employ this means of finding their course when the sky is clouded so as to obscure sun or stars. In the second, he describes the needle as being placed on a pivot, and it is to be noted that this form of the early compass is generally understood to have been the second stage in its evolution. In neither treatise does Neckam represent the instrument as a novelty, but as one in common use.

This is the earliest mention in European literature of the polarity of the magnet, of its directive property, and of the application of that property to the art of navigation.

Almost contemporaneous with, but certainly later than, Neckam, we have the extensively quoted poem, *La Bible*, of Guyot de Provins [**235**]. Its date can be fixed as being later than 1204 and not later than 1209, most probably 1206 [**236**]. It describes a floating compass in use by navigators, and hence does not include the developed form described by Neckam. But it must be remembered that Guyot was a poet, and that he only introduces the compass as illustrative to his theme, whereas Neckam wrote for the instruction of others and had, therefore, to be more strictly accurate in technical detail. By a curious mistake, Guyot was identified by Pasquier [**237**] with another writer, Hugues de Bercy, a French poet of the time of St. Louis. Although this error was corrected by Barbazan [**238**] in 1759, and by the Comte de Caylus [**239**] in 1774, the belief that Guyot and de Bercy were one and the same person persists down to the present day [**240**]. Another side issue was the misinterpretation of the word "manate" which occurs in Guyot's poem. It really means "magnet," but was transcribed by Pasquier [**241**] as "marinette." Hence the statement, frequently made by encyclopedists, that the early French name for the compass was "marinette." This mistake recurs occasionally down to recent times.

The first attempt, on really scientific lines, at any systematic description of the properties of the magnet was that contained in a letter written in 1209 by Petrus Peregrinus, and addressed to Sigerius de Foucancourt [**242**]. For the full examination of all matters connected with this letter, we are indebted to the researches of Bertelli [**243**]. The author explained how the position of the poles in a spherical mass of lodestone may be determined and showed how they could be distinguished. He suggested or effected several improvements in the nautical compass, and devised the first form of azimuth-compass. That his letter is, for its time, a wonderful production there can be no manner of doubt. But there has been a tendency among some writers [**244**] to overrate his influence, and the statement that he was the first to introduce the pivoted needle is erroneous [**245**].

12—We have thus reached the period at which the directive property and its application to the compass has become generally known. There still remain several references to the compass which must be examined

in order to clear up certain issues which have been raised in connection with the matter.

Soon after Guyot wrote his poem, Cardinal de Vitry published, in 1218, a description of Palestine [**246**] in which he speaks of the compass as a necessary aid to navigation, having seen it in use in 1204. The fact that he refers to it as if it were a novelty, whereas Neckam and Guyot wrote as if it were in common use, might be employed to prove that the introduction of the compass was earlier in the western Mediterranean and the Atlantic seaboard than in the eastern Mediterranean, where de Vitry saw it in use. But the more probable explanation is that the Cardinal had but little experience and less knowledge of matters connected with navigation. He was followed by Thomas of Cantimpre [**247**], who gives a description of a floating-needle compass resembling that of Neckam. The date at which he wrote can only be fixed approximately, between 1228 and 1244 [**248**]. Riccioli [**249**] states that under the reign of St. Louis (1226-1270), French navigators used a floating needle as a compass, but cites no evidence in support of his statement. Michael Scot [**250**], writing some time after July, 1228, refers more than once to the directive property, hinting at its use in navigation, but in each case as if it were already well known. Klaproth [**251**] pointed out that the pseudo-Aristotle quoted by Albertus Magnus and Vincent de Beauvais exhibits some knowledge of the properties of steel. He suggests that the polar properties of the magnet were known to the Arabs before the time of these two writers, i. e., about 1250, and that what was then known came from Arabic sources. Vincent de Beauvais [**252**] refers to the polar and directive properties as if they were novelties, and this might seem to date the arrival of this knowledge in western Europe. But it has been shown that the compass was known in western Europe for at least half a century before the date mentioned, and that there are no conclusive reasons for attributing its introduction to Arabic influences. Here it would be well to remember that the evolution of the idea of polarity, and therefore of a directive property, must have been a slow process. Even as far back as the time of Pliny [**253**] there are references to varieties of lodestone, some of which attract and others that repel. These observations were repeated, or made independently, by Isidorus Hispaliensis [**254**] and the younger Psellus [**255**], but the qualitative law of attraction and repulsion had not been reached.

Poetical references to magnetic polarity now begin to appear more frequently, such as those of Gauthier d'Espinois [**256**] and Guinizelli [**257**]. Schück [**258**] has brought to light a poem, *Unser Vater*, by Krolowiz, dated 1252-1255, in which a clear allusion of the kind is made. Torfaeus, in his Norwegian history [**259**], states that in 1266 the poet Sturla was rewarded for his poem on the death of the Swedish Count Byrgeris by the gift of a compass. If this be reliable, it would indicate that in the middle of the thirteenth century the compass was a novelty in Scandinavia. Quotations by Capmany [**260**] from the works of Raimon Lull, dated 1272, show that the latter was well acquainted with the use of the magnetic needle by navigators. Brunetto Latini [**261**], the tutor of Dante (who also mentions [**262**] it) speaks of the lodestone and magnetic needle. But the story, given by Klaproth [**263**] and repeated by many later writers [**264**], of the visit of Brunetto Latini to England during the reign of Henry III (1216-1272) when Roger Bacon

demonstrated to him the polarity of the magnet, is based upon letters [**265**] which were later acknowledged to be deliberate forgeries [**266**], and one of the most extraordinary things in the history of this subject is Klaproth's omission of this acknowledgment. Bacon himself refers to the subject [**267**], but not as if it were a novelty in his time. The Scottish poet Barbour, writing in 1375, says [**268**] that his hero, King Robert the Bruce, "na needil had na stane" to direct his course from Cantyre to Carrick in 1306, from which we may conclude that some form of compass was known in Scotland by the latter half of the fourteenth century.

13—Among the many statements made with regard to the origin of the compass, none has attained wider currency than that which attributes its discovery in 1302 to Flavio Gioja, a native of Amalfi, a small seaport in southern Italy. The history of this legend—for such it is, in spite of its being supported by official authority [**269**], and of its being quoted as genuine in a serious history of science of recent date—is interesting, if for no other reason than that it provided the occasion for the important historical researches of Bertelli [**270**]. It begins with a passage in the historical work of Flavio Blondo [**271**], who, writing about 1450, said: "*Sed fama est qua Amalphitanos audivimus gloriam, magnetis usum, cujus adminiculo navigantes ad arctem diriguntur, Amalphi fuisse inventus quicquid vero habeat in ea re veritas, certum est id noctu navigandi auxilium priscis omnino fuisse incognitum.*" He thus made a claim on behalf of the Amalphian navigators *generally* to the invention and first use of the compass. Four points must be noted in connection with this claim. First, the discovery is not ascribed to any particular individual; second, no date is assigned to it; third, the statement was made at least two hundred and fifty years after the compass in a primitive form—possibly in an improved form—was first known in western Europe; fourth, the statement was not accompanied by, nor is there any indication that it was based upon, any systematic examination of the facts of the case. The next stage comes about five years later, when Antonio Beccadelli, otherwise known as Antony of Bologna, or "the Panormitan," repeated in one of his poems the statement that the compass was first used by the Amalphians, although he does not credit them with the invention. His verse was not published until fully a century later, possibly first by Torello [**272**], certainly by Mazella [**273**] in 1586. Meanwhile, in 1489, Polydore Vergil [**274**] had said that it was not at all clear who was the inventor. The third stage was that at which Baptista Pio [**275**], quoting Blondo in 1511, makes the remark, "*Amalphi in Campania veteri magnetis usum inventus a Flavio traditur.*" Fourth, there came Giraldus, who had two contributions to make. In the first [**276**], possibly assignable to the early part of the sixteenth century, he credits the Amalphians with the earliest use of the magnetic needle, and describes what appears to be a circular compass-card attached to it. In 1539, Collenuccio [**277**] wrote to much the same effect. In his second contribution, of 1580, Giraldus [**278**] quoted Baptista Pio, but in doing so showed an entire misconception of the position. He says, "*Sed non multis retro seculis Amalfis in Campaniae oppido, antiquis navigandi usus incognitus per magnetem et chalybem, quorum indicio nautae ad polos diriguntur a Flavio quadam excogitatus traditur.*" He thus ascribed the invention to a person named Flavio, whereas Flavio

was the name of the author of the original statement. This was the origin of the legend, and in this form it was repeated by Lopez [**279**], Cardan [**280**], Belon [**281**], Gasser [**282**], Lemnius [**283**], Bartolomeo [**284**], Aldrovandi [**285**], and others [**286**] in later times. But matters were made much worse when, in 1586, Mazella [**287**] gave a surname, Gioja, to the supposed inventor. He said, "*In Amalphi nell' anno 1300 fu* (*gloria degli Amalfitani*) *ritrovata di Flavio di Gioja la Bussola, tanto necessaria a naviganti.*" For this ascription to a person and a year no warrant was produced. It may seem difficult to account for the appearance of this surname, except on the hypothesis that it belonged to some actual individual. But the similarity between the French "Guyot" and the supposititious Italian "Gioja" suggests the explanation that Mazella had read somewhere about the former, and had given his name the Italian form. Be this as it may, the confusion was not lessened when Ortelio [**288**] gave the name of the inventor as Giovanni Gioja or Giri, and made the further mistake of shifting the scene of discovery from Amalphi to Melphi. During the three and a half centuries which have since elapsed, the error has been repeated so persistently that it might have passed permanently into the historical literature of science, had Bertelli [**289**] not shown how the legend arose. On the other side, it has had its patriotic defenders in Grimaldi [**290**] and Venanson [**291**]. It has also been supported by Briet [**292**], Voltaire [**293**], and others [**294**]. For reference to criticisms other than those of Bertelli, Signorelli [**295**], Camera [**296**], and Fiucati [**297**] may be consulted. Lastly, it may be mentioned that a statue to the mythical Gioja has been erected in the Exchange at Naples, and that the six hundredth anniversary of his supposed discovery was celebrated at Amalphi in 1901 [**298**].

With regard to this claim of Gioja—apart altogether from what has been stated above—it need only be said that the year to which it is assigned, 1302, is at least a century later than Neckam's description of the compass.

14—Before leaving this part of the subject, the reader will doubtless have noticed that much of the evidence collected on the history of the compass has had to depend on historians, poets, and others who are not concerned with the actual use of the instrument, and it will be obvious that it must be difficult to obtain such direct evidence of its use. Indeed, there are indications that the general introduction of the compass in western Europe was hindered by fears that those who used it might be accused of practicing magical arts. Voltaire [**299**] said that the first use of the compass was by the English during the reign of Edward III (1327-1377), but he gave no authority for his statement. That it was then in use can, however, be proved. Nicholas [**300**] cited instances from official records showing that, in 1338 and 1345, certain ships of the British Navy were supplied with "sailing needles and dial," as the compass was then termed. In one case they were purchased in Holland. This is the earliest record of the actual use of the compass in a given ship. Capmany [**301**] reported that while the compass is not mentioned in the inventory of a ship fitted out at Barcelona in 1331, nor in similar lists for the galleys of Don Pedro IV of Aragon in 1364, it is mentioned in the chronicle of Don Pedro Nino under 1403, and in the galley inventories of Alfonso V of Aragon in 1409.

The later history of the compass is only concerned with its technical

improvement as an instrument, no additional principle in terrestrial magnetism being involved. The matter need not, therefore, be pursued further, except to refer the reader to the work of Schück [**302**] for information on these later aspects of the question.

15—We have thus summarized the available evidence as to the origin of the knowledge of the directive property of a magnet in the Earth's field and of the application of this property to the nautical compass. It has been considered desirable that the facts of the case should be kept in prominent view, to the exclusion of opinion too often based on incomplete examination of the material. And it is believed that in this summary no original record of importance has been omitted. The case is therefore ready for such conclusions as may seem possible. But before these are stated, it is well that some general principles receive attention.

Granted a widely diffused knowledge among ancient peoples of the attractive qualities of the lodestone, the probable sequence of further discovery may be considered. Here we have to remember that the historical development of a science in the darker ages was very unlike the intensive processes of investigation in a modern physical laboratory. But it is reasonable to suppose that there were four stages in development: The magnetization of iron or steel; the polarity of a magnet; the directive property in the Earth's field; the application of that property in the construction of a compass. But we have no evidence that these constituted the general order of discovery in the case of any particular country or people. For instance, in China, the first reliable mention of the directive property is in connection with a magnetized needle; in Europe it is first clearly stated as a property of the lodestone. It has also to be noted that, at a certain stage, while there was a belief in some countries—China and the eastern Mediterranean, for example—that the directive property was evoked in iron or steel by the lodestone, there was no recognition of the fact that the property was already present in the lodestone itself.

To the science of to-day the qualitative laws of magnetic attraction and repulsion, and the elementary fact of the directive property, appear to be extremely simple conceptions. But it is less easy to appreciate the difficulty facing the investigator of, say, the tenth century. Polarity, at that time, would be an entirely new conception; the Greeks, and still more the Latins, had no word with which to express the idea. And the difficulty of expression would not be lessened by the circumstance that it was an age in which progress was believed to lie in wrangling over words rather than considering objective facts, and when argument was regarded as superior to observation or experiment. Add to this the lack of communication between learned men, and we cannot be surprised that advance was slow and hesitating; that it was frequently held up in the blind alleys of verbal disputation; and that the course of discovery may, in particular countries or races, have taken a direction which it is now impossible to retrace. It is a curious reflection that the study of terrestrial magnetism received its main impulse, not from the monk in his cell, nor from the professor in his academic chair, but from a class of men furthest removed from all such influences—the men who, as Solomon said, had "knowledge of the sea." The world owes more to its sailors than it has generally acknowledged.

On general grounds, it seems obvious that some considerable time must have intervened between the discovery of the directive property and its application to the compass. The difficulty is the determination of that interval. In China, it appears to have extended over two centuries, largely owing to the decay of maritime activity among the Chinese. As regards western Europe, we have no knowledge of its duration, for the first mention of the directive property is made along with the description of the first primitive compass.

16—To come nearer a final conclusion, we may proceed to the elimination of certain claims to priority. That the "magnetic chariot" of the Chinese was the earliest attempt at a compass must be excluded for reasons already given. Those made for the Phenicians, Egyptians, Etruscans, and the Greeks and Latins of classical times must also be set aside for lack of evidence. The same applies to the theory of Benjamin with regard to the Finns. Lastly, the claims made on behalf of particular individuals, Marco Polo, Pacifico, Gerbert, and Gioja, have been examined and rejected. This leaves us with three areas, or groups of races, in which the early knowledge of terrestrial magnetism may have developed; the Chinese, the Arabs, and the peoples of western Europe. The opinion most generally held hitherto, that it began with the first, and was carried by the second to the third of these groups, has already been explained and adversely criticized.

The final conclusion may be stated in the following form:

(I) That while it is possible that the Chinese were acquainted with the directive property of a magnet by 1093 A. D., they made no further use of that property for at least two hundred years thereafter.

(II) That there is no evidence of the origin of any such knowledge among the Arabs, and it is improbable that they transmitted any information on the matter to Europe, their earliest mention of the compass being nearly half a century after its first mention in Europe.

(III) That the compass was in use in western Europe by 1187 A. D., and taking into consideration the fact that the directive property must have been discovered much earlier, it is most probable that a knowledge of that property and its application in western Europe was of independent origin and as early as, if not earlier than, that in China.

Bibliographical References and Notes

[As a rule, only original sources of information are given. Secondary references are only mentioned when they include critical or additional matter of importance, or when there appears to be error in fact or interpretation. References which have not been examined and verified are indicated by an asterisk.]

[1] Gilbert, *De Magnete*, Chiswick Press, ed. vi, and bk. II, ch. vi, seems to have been the first to have clear ideas on this point. His "orbis virtutis," defined as "all that space through which the virtue of any lodestone extends," is the magnetic field. See Kelvin, *Popular Lectures and Addresses*, London, 1891, III, 246.

[2] Gaubil, *Observations mathématiques, astronomiques, géographiques, chronologiques, et physiques, tirées des anciens livres chinois*. Ed. by Souchet, Paris, 1729, 3 vols. Vols. II and III dealing with Chinese astronomy, are by Gaubil.

[3] Duhalde, *Description géographique, historique, et physique de l'Empire de la Chine et de Tartarie Chinoise*. Paris, 1735. English trans. (here referred to) by Brookes, *General history of China*, London, 1736.

[4] Mailla, *Histoire générale de la Chine*, Paris, 1377, 13 vols.

[5] Amiot, *Mémoires concernant l'histoire, les sciences, les arts, les moeurs, les usages, etc., des Chinois.* Paris, 1776-91. The *Abrégé chronologique de l'histoire universelle de l'Empire Chinois*, by Amiot, is in XIII, 74-308.

[6] Hager, *Memoria sulla bussola orientale*, Pavia, 1809 and 1810.

[7] Klaproth, *Lettre à M. le Baron A. de Humboldt sur l'invention de la Boussole.* Paris, 1834, to which reference is here made. German ed., Leipsic, 1885.

[8] Biot, *C. R. Acad. sci.*, XIX, 822-829 (1844).

[9] The earliest supposed reference to the south-pointing chariot is in the *Kiu-ku-tzi*, written in the 4th century B. C. It is there stated (sect. 10, quoted by Hirth, *Ancient history of China*, New York, 1911, 128) that the people of Chong use the contrivance when seeking for supplies of jade. But the authenticity of this work has been disputed. (See Giles, *Adversaria Sinica*, Shanghai, 1905, 110; but compare the criticisms of Hashimoto, *Memoirs of the Research Department of the Toyo Bunko*, Tokyo, 1926, No. 1, 74-75.) Another, possibly more distant, reference is found in the *Han-fei-tsen* (quoted by Hirth, 128), written before 233 B. C., which states that "the early kings constructed the *ssi-nan* or 'south-pointer' in order to show the position of morning and evening." Biot [8] 822, makes this out to be the earliest reference, and places it in the 4th century B. C. The first conclusion is doubtful; the second is in error. Gaubil [2] II, 94-95, through whom it first came to be known in Europe, quotes from the Chinese annals *Thoung-kian-kang-mou*, but gives no exact reference. Mailla [4] I, 316, refers the invention to the later time of Tcheoung-kong, but his editor, Abbé Grosier, paraphrases the story from that part of the annals known as the *Wai-ki.* Amiot [5] XIII, 227, also uses the annals, referring to the *Tsien-pien* under "Hoang-Ti." Klaproth [7] 72-73, quotes from the same source as Gaubil, Imperial Ed., 1707, *Ou-ti-ki*, fol. 22, v, and gives a translation of the passage. It may be added that the story is not given by Se-ma-Tsien, the most reliable of the ancient Chinese historians. "On remarquera que Se-ma-Tsien omet les légendes qui rapportent l'invention de tous les arts à l'époque de Hoang-Ti." (Chavannes, *Mémoires historiques de Se-ma-Tsien*, Paris, 1895, I, 35, note 1.) Mottelay, *Bibliographical history of electricity and magnetism*, London, 1922, puts it under 2637 B. C., for reasons given, relates the incident of the fog as a natural occurrence, and says it was a female figure which stood on the chariot. For the two latter statements there is not sufficient authority. His reference to Souchet should have been ascribed to Gaubil, and that to Saillant and Nyon to Amiot. With regard to the fog raised by Tchi-Yeou, the belief that such phenomena are producible by enchantment continued until comparatively recent times. See Yule's ed. of *Marco Polo*, London, 1871, I, 92. For the case of a genuine fog interfering with the progress of a battle in 1762, see his note, p. 100, and the reference there quoted.

[10] For a fairly full account of the European literature, particularly of the writings of the Catholic missionaries, down to 1825, see Morrison, *Chinese Miscellany*, London, 1825.

[11] It is somewhat difficult to give a strictly chronological arrangement of the different authorities to whom this version of the legend can be referred, and in what follows there may be departures from the best ascertained order. The same applies to [12] below.

The *Tai-ping-yu-lan*, a cyclopedia of the 10th century A. D., quotes the *Kiu-ku-tzi* (but see [9] above) to the following effect: "The Su-shon offered a white pheasant to Wou-wang. Lest they might lose their way on the journey, Tcheou-kung constructed the south-pointing chariot to accompany them" (Hirth [9] 128). See also Legge, *Chinese classics* V, *Shu-king*, 537, who holds that the first genuine mention of the south-pointing chariot in this connection is not older than the 2nd century A. D. Also Hashimoto [9], 70, note 5, regarding Legge's source of information. (Parker, *New China Review*, 1919-22, has examined the general question of the authenticity of Chinese writings of this period.) The *Thoung-kian-kang-mou*, 1701 ed., I, fol. 9, quotes from the memoirs of Se-ma-Tsien. The passage, as Klaproth [7] 82, pointed out, does not occur in the 1707 edition, but is found in the Manchu and other editions. As noted in [9], it is not in Chavannes' elaborate edition [9] of Se-ma-Tsien. The official history of the Song dynasty (420-478 A. D.) written by Shen-yo (441-513 A. D.), as quoted by Giles [9] 111, gives a fairly full account, and attributes the invention to Tcheou-kung. Klaproth [7] 71, quotes from the *Yeou-hio-kou-szu-khiong-liu*, an encyclopedia written about 100 B. C., the statement that Tcheou-kung made the south-pointing chariot and the compass (liv. IV, fol. II, v. 1), but Bertelli, *Mem. Acc. Nuovi Lincei*, IX, has shown that the words "and the compass" are an interpolation of later date. Gaubil [2] II, 95, mentions the ascription to Tcheou-kung, but gives no specific reference. Giles [9] 219-222, quotes from the chapter on "Chariots" in the history of the Song dynasty.

This passage recounts the original story of Hoang-Ti, also its later form now under reference, and then passes on to the further history of the invention. Mottelay's chronological account [9], although of considerable value generally, contains several errors, nearly all of which are traceable to Humboldt, who was very strongly prejudiced in favor of Chinese priority. Under B. C. 1110, Mottelay states that "Tcheoung-kung is said to have at this date taught the use of the needle-compass to the envoys from Youa-tchang." But there is no mention of the magnetic needle or compass in any Chinese writing of that period, or dealing with that period, and the statement that the south-pointing chariot contained a magnetic compass is an entirely unwarranted addition. Under 1022 B. C., he states that "at this period the Chinese magnetic cars held a floating needle," another example from Humboldt. He refers to Se-ma-Tsien for confirmation, but, as previously explained, the passage is extremely doubtful, and in any case makes no allusion to a floating needle. Under 1068 B. C. he quotes Humboldt, *Asie Centrale*, Paris, 1843, I, xxxviii-xlii, to the effect that in that year the magnetic chariots were used as a guide "across the boundless plains of Tartary," for which there is not a scrap of evidence. Thus Humboldt's sweeping statements have found wide currency, even down to the present day. They are given in an unrestricted, or even amplified, form in Knight's *Dictionary of practical mechanics*, col. 1396.

It should be mentioned that a curious sequel to the story of the Tonquin embassy and the south-pointing chariot was given in the *Ki-kin-chu*, written by Tsui-pau during the Tsin dynasty. (See *J. R. Asiat. Soc., N. China Branch*, N. S. XI, 123). It states that the officers accompanying the returning ambassadors came back in the same carriages *in a direction opposite to that in which they pointed.* This is, of course, a spurious, and very late, addition to the story.

[**12**] The history of the Song dynasty, composed in the 5th century A. D., is the source generally used. Hirth [**9**] 129, quotes from ch. XVIII, 4, that the secret of the south-pointing chariot had been lost for many centuries, but was rediscovered by the astronomer Chang-hong (78-139 A. D.). His model was lost in the troublous times at the end of the Han dynasty, and was subsequently forgotten. This is also quoted by Klaproth [**7**] 83, but with a difference in date. Several authors state that the scholar Ma-kium, who lived about 235 A. D., reinvented the chariot, and that it was placed in the hall known as *Thoung-houa-tian*, where many curiosities were kept. Klaproth [**7**] 83, quotes this from the *Thoung-kian-kang-mou*, 1707, ed. xv, fol. 29, and also from the treatise on ceremonies which forms part of the history of the Song dynasty. This latter source is also used by Giles [**9**] 111. Parker, in *China Review*, XVIII, 197, quotes the *Sung-shu* to show that the chariot was made again under the emperors Shi-Hu (532 A. D.) and Yan-hing (about 400 A. D.), but Hashimoto [**9**] 72-73, remarks that Parker drew conclusions from a text which he misunderstood. According to Hirth [**9**] 131, the model made under Yan-hing is described in the biography of its engineer, *Nan-tsi-shu*, LII, 15; that it had no machinery at all, but whenever it was put in motion a man had to step inside in order to work the contrivance. The two models referred to fell into the hands of the Song emperors in 417 A. D., but "the machinery being too coarse, the south-pointer showed so often in the wrong direction that men were required to set it right again." Giles [**9**] 111, in the passage referred to above, quotes a statement that the south-pointing chariots made by the Thibetan tribes did not work well, and had to be taken slowly round any turn. It also represents them as having been made by an ingenious mechanician, Ysou-tsoung-tchi. The circumstances in which Wu-ti's chariot was finally made by Ma-yo are quoted by Klaproth [**7**] 89. Hirth [**9**] 132, refers to the *Chan-ye-tsien-tsai*, a work of the 8th century and quoted in the *Ko-chi-king-yuan*, XXIX, 25, as showing that in 692 A. D., a mechanic of Hai-chow constructed a chariot which showed the twelve hours of the day, by the shaft being pointed due south. But Hashimoto [**9**] 87, places a widely different construction on the passage. The same encyclopedia, p. 24, describes another south-pointing chariot as being 7½ inches long and 15 inches high. Tchin-in, quoted by Klaproth [**7**] 76, and others, said that nothing was known of the ancient form of these chariots; that the emperor Hian-tsoung (806-820 A. D.) had one made; that it consisted of a pavilion at four angles of which were wooden dragons; that on the pavilion was placed a wooden figure, the hand of which always pointed to the south, however the chariot might turn; and that some say that the chariot carried a compass. This is obviously a very late commentary. The same note states that one of the drums termed *Ki-li-kou* was added to the chariot. This construction is referred to in the *Sung-shu*, CXLIX, 15, quoted by Hirth [**9**] 131, as being based on a complicated system of cog-wheels, and that it was reconstructed by the emperor Jin-tsoung in 1027 A. D. Another was made for the emperor Hiu-tsoung in 1107. Giles [**9**] 112, refers to the *Poei-wen-yun-fu* as giving other allusions, but containing nothing of additional interest.

[**13**] Klaproth [7] 90-91, from the *Thoung-kian-kang-mou*, 1707, ed., XXIV, fol. 22, 23.

[**14**] *San-thsai-thou-hoei*, V, fol. 10, ed. by Wang-khi.

[**15**] Klaproth [7] Plate II, Fig. A. Another, Fig. B, is taken from a Japanese cyclopedia of 1609. Klaproth's figures are reproduced by Davies in Thomson's *British annual*, 1837, and his Fig. B is given in the *J. Frank. Inst.*, XVIII, 69, and by Benjamin, *Intellectual rise in electricity*, London, 1895, 73. With regard to the alignment of the walls of buildings by means of the south-pointing chariot, Gaubil [2] III, 37, refers to the matter and to the attention paid to exactness. But the rules there given are based on astronomical principles, and do not mention either the south-pointing chariot or the compass.

[**16**] Klaproth [7] 93-94, cites passages from Kai-bara-Tok-sin, author of *Wa-zi-su*, published 1696, who quotes from an older Japanese history, *Nippon-ki*. The dates of construction are given as 658 and 666 A. D. Klaproth adds that, nevertheless, the lodestone was not known in Japan before 713 A. D. I have not been able to trace his authority for this statement. In Knight's *Dictionary* [**11**] 1397, it is stated that in 543 A. D., "the wheel which shows the south was sent to the Mikado by the court of Petsi (Korea)." There is no entry to this effect under that year in the *Nihongi* (Aston's translation, *Trans. and Proc. Japan Soc.*, London, 1896), which gives the two instances quoted by Klaproth.

[**17**] For a discussion of Chinese chronology, see Freret, *Mém. Acad. des Inscr.*, XVIII; Ideler, *Berlin Akad. Abh.* 1837, and his **Handbuch der mathematischen und technischen Chronologie*, Berlin, 1825-26. Remarks of a general kind are given by Davies [**15**]; also by Goguet, *Origine des lois, des arts, et des sciences*, Paris, 1758, III, 293, who distrusted all Chinese records before the "Burning of the Books." See references and details given by him. For the chronology of Se-ma-Tsien, who rejected all dates before 841 B. C., see Chavannes [**9**] I, clxxxvii-clxxxviii.

[**18**] For comparatively recent criticism by the Chinese of their own literature, see "J. E." (Rev. J. Edkins), *China Herald*, March 1857, reprinted in the *Chinese and Japanese repository*, London, 1863-65, I, 66-69. Also Tang-Leang-Li, *Foundations of modern China*, London, 1928, 2, 6. He makes the somewhat uncompromising statement that the greater part of the records supposed to have escaped the "Burning of the Books" are forgeries by the scholars of the Han dynasty. He quotes authorities in support of his conclusions.

[**19**] Legge [**11**].

[**20**] See [**9**], [**11**].

[**21**] Quoted by Giles [**9**] 111, from Shen-yo's history of the Song dynasty.

[**22**] For lists of words in different languages to denote the lodestone, magnet, and compass, see Klaproth [7] 13-38; Martin, (a) *Atti Acc. Nuovi Lincei*, XVIII, 17-32, 97-123, and (b) *Mém. Acad. Inscr.*, VI, part i; Buttmann, *Musæum der Alterthumswissenschaft* II, 5-52, 102-104; Robertson, *Historical disquisition concerning ancient India*, London, 1791, 227; Badger's edition of the *Travels of Ludovico di Vartema*, Hakluyt Soc.; Davies [**15**] 250-257; Edkins, *J. R. Asiat. Soc. N. China Branch*, VI, 73-104; *Niebuhr,* Reisenbeschreibung nach Arabien und andern umliegenden Ländern*, Kopenhagen, 1778, II, 206-207; Brunot, *Notes lexicologiques sur le vocabulaire maritime de Rabat et Sale*, Paris, 1920. Also S. P. Thompson's notes on Gilbert [**1**].

[**23**] Gaubil [**2**] II, 94-95. Also in [**5**] XVI, 179, note 1, where he says that it was under the reign of Hian-tsoung (806-820 A. D.) that the Chinese gave to the compass the form in which he then knew it. Duhalde [**3**] I, 273, also gives the same interpretation of the contrivance, apparently repeating the opinion of Chinese commentators of his own time. Note that any purely Chinese reference to the compass or magnetic needle in association with, or in explanation of, the south-pointing chariot is of comparatively recent date, and certainly subsequent to the introduction of the compass in other countries.

[**24**] See text and [**13**].

[**25**] Giles [**9**] 219-222.

[**26**] Hashimoto [**9**]. The first of his final conclusions is that the south-pointing chariot had nothing to do with the lodestone or magnetic needle. For reference to Mikami, see *Isis*, 1928, XI, 124. Also Moule, *Toung Pao*, Leyden, 1924, XXIII, 83-97.

[**27**] Klaproth [7] 85-86. See also the remarks of Benjamin [**15**] 70, where the suggestion is made that the "south-pointing" of these chariots refers to their position

on ceremonial occasions. He quotes in support the account of the funeral of the King of Chow (1102 B. C.) as detailed in the *Shu-king*.

[**28**] Hirth [**9**] 131.

[**29**] Tang Leang Li [**18**].

[**30**] References have already been given to the writings of the missionaries who were the first Europeans to put forward the Chinese claim to priority, as based on the south-pointing chariot. To these may be added Martini, *Histoire de la Chine*, Paris, 1692, 106; Humboldt [**11**]; Wylie, *Chinese researches*, Shanghai, 1897, part III, 155. Lord Kelvin [**1**] 229-232, accepted Duhalde's account [**3**] on the ground that "the instrument which the Emperor Hoang-Ti is said to have used cannot possibly have been anything but a compass, as nothing else could have done what is said to have been done." But the question as to how it was done must be secondary, at present, to the other, whether it was done at all. The general opinion has been negative. Klaproth [**7**] 78-79, practically rejected it. Legge [**11**] held that the statements were fables invented to illustrate later knowledge. Chalmers, *China review*, XIX, 52, attributed the story to the national vanity of the Chinese, "who appropriate to themselves the invention of all sorts of things." Bertelli, *Mem. Acc. Nuovi, Lincei*, IX, only gave it a very qualified support. The opinions of Giles and Hashimoto have already been quoted. See also the article by van Hee on the *Chou-jen-Chuan* of Yuan Yuan, in *Isis*, VIII, 102-118.

On the other side, an article in *Nature*, Apr. 27, 1876, signed "K," supports the Chinese claim. But few details are given, and it also includes several erroneous statements with regard to Guyot de Provins and "Peter Adsiger." Another article in the same journal, July 30, 1891, copied from the *North China Herald*, also supports the claim, but many of the statements made are unauthenticated. Volpicelli, *Atti Acc. Nuovi Lincei* XIX, 205-218, and Beazley, *Dawn of modern geography*, London, 1897-1906, I, 51, both state that the Chinese were acquainted with the directive property before the Christian era. But neither condescends to any proof of this proposition. Hirth [**9**], who has examined the subject very carefully and has summarized it in chronological form, seems to hold the view that the original south-pointing chariot may have been an application of the directive property; that after some centuries the secret was lost; and that attempts made to evolve some mechanism which would produce the desired effect only resulted in the construction of a measurer of distance traveled. The description of the chariot by Amiot [**5**] XIII, 227, suggested to Azuni, *Dissertation sur l'origine de la boussole*, Florence, 1795, Venice, 1797, Paris, 1805, 67, that it was really a globe with a geographical chart upon it. Some of the later descriptions would seem to suggest a sun-dial. General remarks and criticisms will be found in Schück, *Die Natur*, Halle, XL, 606-609, 613-615; De Saussure, *Arch. Sci. Phys.*, 5th period, V, 149-181, 259-291, particularly on the interpretation of the Chinese words denoting the south-pointing chariot and the compass.

[**31**] The following example may be given for what it is worth: "When Confucius died (478 B. C.), he was buried on a hill, Kiu-fan, in Shantung, and there his disciples remained for three years, and Toz-kung for six years, during which time he covered the coffin with lodestone, which prevented the emperor Chin from destroying the tomb. For when he sent to have it opened, the mattocks were all arrested at the first blow by the attraction, and the soldiers were dragged to the ground by the action of the magnets on their coats of mail, so that the tomb remained intact." (No. 18 of the Chinese fables translated by Bowring from Gonsalvez, *Arte Chine*. Reprinted in *Chinese and Japanese Repository*, I, 248-254.) References to other cases in which the lodestone is mentioned in Chinese literature are given by Giles [**9**] 113. One of the early references is that by Kono-pho, who wrote on the magnet in 324 A. D. If this is genuine, it is curious, as Benjamin [**15**] 74, 81, points out, that the phenomena of magnetic attraction should be there explained according to a theory current among the Greeks eight centuries earlier, and on lines entirely foreign to Chinese conceptions. (See Pliny, *Natural History*, Bostock and Riley's ed. London, 1857, IV, 206, VI, 209.) Hashimoto, [**9**] 84, has also given some early references, the earliest being 249-237 B. C.

[**32**] Klaproth [**7**] 66-67. Hashimoto [**9**] 84-85, could not find this passage in the *Choue-wen*, and concludes that Klaproth was in error. He has brought to light a passage in the *Lun-heng*, written by Wan-chung (30-100 A. D.) which simply states that "a lodestone attracts a needle," but as proof of a knowledge of the directive property this is open to the same objections as are stated in the text against Klaproth's extract from the *Choue-wen*. There is also, according to Hashimoto, [**9**] 85, a passage to the same effect in the *Wa-myo-rui-ju-sho*, ch. II, a Japanese work of 923-930 A. D.

[**33**] Klaproth [**7**] 66.

[**34**] For example, Klaproth [**7**] 67, 84. Benjamin, [**15**] 75, deals with this point, and quotes from La Couperie, *Western origin of Chinese civilization*, London, 1894. Also from *Trans. Asiat. Soc. Japan*, VIII, 475, and *J. Asiat. Soc. N. China Branch*, N. S. XI, 123. But the origin of the story is found along with other apocryphal instances of the use of the south-pointing chariots. See [**11**]

[**35**] Klaproth [**7**] 67. Humboldt, *Examen critique de l'histoire de la géographie du nouveau continent*, Paris, 1836-39, III, 36-37. He adds that the Chinese "avaient reconnu aussi que la chaleur diminue cette force directrice." But he omits to state that this recognition is only found in an encyclopedia, *Ou-thsa-tsou*, compiled at the end of the 16th century, and that we have no guarantee of the purity of its text.

[**36**] Gaubil [**2**] 95.

[**37**] Wylie [**30**] 155.

[**38**] Hirth [**9**], Chronological summary under 700 A. D. Hashimoto, [**9**] 85, also failed to find Wylie's passage, either in the life of Yih-hing, or in the *Tang-shu*, which mentions the principal events in the life of Yih-hing. A passage in the *Tang-shu* resembles it, but has nothing to do with the magnetic needle.

[**39**] See Hirth [**9**] 132.

[**40**] Klaproth [**7**] 68.

[**41**] The *Pen-tsao-kang-muh* was completed about 1580 A. D.

[**42**] Klaproth [**7**] 67.

[**43**] Klaproth [**7**] 95. For the reasons given in the text immediately after this reference, it is almost certain that Klaproth was wrong in his conclusion. But it has been accepted by Beazley, [**30**] I, 490, who states quite explicitly that the Chinese used the compass in the third century A. D. For this there is no evidence. Speck, *Handelsgeschichte des Alterthums*, Leipsic, 1900, I, 29, 209, went even further. He thought the Chinese used the compass in navigation from the first century A. D. But no reasons are given for this conclusion.

[**44**] *Travels of Fa-Hian and Sung-yun*, trans. by Beal, London, 1869. See also Remusat, *Mém. Acad. Inscr.*, XIII, and his translation,* *Foe-koue-ki*, new edition, with notes by Klaproth and Landresse, Paris, 1836. Reference should also be made to the passage relating to Fa-hian in Hirth and Rockhill's *Chau-jukua; his work on the Chinese and Arab trade in the twelfth and thirteenth centuries, entitled Chu-fan-chi*, St. Petersburg, 1911, 27.

[**45**] Renaudot, *Anciennes relations des Indes et de la Chine*, Paris, 1717, English trans., London, 1753, 142. With regard to the history of the documents upon which Renaudot based his *Relations*, see *J. des Savans*, Dec. 1764, 315; Robertson, [**22**] 224; and chiefly Reinaud, *Relations des voyages faits par les Arabes et les Persans dans l'Inde et à la Chine*, Paris, 1845. Also, Ferrand, *Voyage du marchand arabe Sulaiman en Inde et en Chine, rédigé en 851, suivi de remarques par Abu Zayd Hassan*, Paris, 1922.

[**46**] In addition to Hirth and Rockhill [**44**] and Reinaud [**45**], the following may be consulted: Chavannes, *Les religieux éminents, qui allèrent chercher la loi dans les pays d'Occident* and *Mémoire composé à l'époque de la grande dynastie Tang, par I-Tsing*, Paris, 1904; two important papers by Ferrand, *J. Asiat.*, 1919 and 1922, and another in 1924; Levi, *J. Asiat.*, 1900, and Braddell, *Chinese and Japanese Repository*, III, 57-72, 113-128 (a good summary, but quotes no authorities). With regard to the difficulties and risks of navigation by the Chinese in voyages to (what appears to be) the Philippine Islands, see Yule's *Marco Polo* [**9**], bk. III, ch. iv.

In none of these accounts of early maritime activity in eastern seas is there any mention of the compass, and in the first of the references it is explicitly stated that the pilots had to rely on "the regularity of the monsoons and steer solely by the Sun, moon, and stars." De Saussure, [**30**] 268, has suggested that the compass was not an absolutely necessary instrument in navigation during voyages of the kind; that from China to the Straits of Malacca they must have sailed along the coast; and that in the Indian Ocean they were guided as well as helped by the trade-winds or monsoon. There is some evidence in these records of early voyages that navigation from the Straits to Ceylon was by way of the Nicobars or Andamans, from which the northeast monsoon would give them a good "slant" for the Coromandel Coast, which they could then follow to Ceylon.

[**47**] Humboldt, *Asie Centrale*, I, xli, and *Cosmos*, London, 1849, II, 630. The most recent repetition of Humboldt's errors will be found in Sidgwick and Tyler's *Short history of science*, New York, 1918.

[**48**] Hirth [**9**] 133-134. This is referred to in the text as the earliest mention of the use of the compass in China. Another of nearly the same date is that quoted by Parker, *China Review*, XVIII, 197, and Edkins, *J. R. Asiat. Soc. N. China Branch*, XI, 128-134, according to which it was used by a Chinese envoy to Korea in 1122. But Hashimoto, [**9**] 88, says he has been unable to find any passage of the kind in any Chinese work. He refers, however, to another in the *Tung-hua-lu*, written by Tseng San-i about the end of the twelfth century, which speaks of the compass, and even describes the deviation of the magnetic needle.

[**49**] Hirth and Rockhill [**44**] ch. 46, 176. See also Schaer, *Arch. Gesch. Naturw. Tech.*, VI, 329-337.

[**50**] *Chrestomathie Chinoise*, Paris, 1833, 21, etc. A French translation is given by Remusat in *Nouvelles annales des voyages*, Paris, 1819, III, and in his **Nouveau mêlanges Asiatiques*, Paris, 1828, I.

[**51**] Giles, *Chinese biographical dictionary*, London, 1898.

[**52**] Cordier's edition of *Marco Polo*, II, 277, gives it in the following form:

> "With Kun-lun to starboard, and larboard the Cheu,
> Keep conning your compass whatever you do,
> Or to Davy Jones' locker go vessel and crew."

It is also referred to by Gaubil in [**5**] XIV, 53.

[**53**] Klaproth, [**7**] 97, quotes the cyclopedia *Ou-thsa-tsou*, written at the end of the sixteenth century. Carletti, *Ragionamenti sopra le cose vedute nei suoi viaggi*, Florence, 1701, 275.

[**54**] Nicolas Wetsen, *Noord en Oost Tartarye*, Amsterdam, 1705, 56.

[**55**] Carletti [**53**] 275. Fournier, *Hydrographie*, Paris, 1643, XI, i. Duhalde, [**3**] 283, however, refers to a compass, apparently with a pivotted needle, in 1687.

[**56**] Davies [**15**] 291. Also *Encyclopedia Britannica*, 9th ed. VI, 226.

[**57**] Staunton, *Authentic account of an embassy to the emperor of China*, London, 1747, I, 441. Fleuriais, *Annu. Bur. longit.*, Paris, 1894.

[**58**] De Saussure [**30**], where an explanation of the origin of the division of the circle into 12 or 24 parts in given. See also Dissertation III, *On the navigation and compass of the Chinese*, by Lord Macartney, in Vincent's *Commerce and navigation of the ancients in the Indian Ocean*, London, 1807, II, 656-660.

[**59**] The earliest mention of the division of the compass-card or circle into 32 points would appear to be that by Chaucer, *Treatise on the astrolabe*, ed. by Skeat; London, 1872, Part II, 31, line 6. For the origin of Chaucer's work, see note at the end of Halliwell's edition of Mandeville's *Travels*. But it is a mistake (*Principal facts of the Earth's magnetism*, Washington, 1909, 21) to read the passage in Chaucer as meaning that the actual adoption "by the English" of the 32-point compass was "delayed" until 1391; the year in which Chaucer wrote.

[**60**] Barrow, *Voyage to Cochin China in the year 1792-3*, London, 1806.

[**61**] Przyluski, *La divination par l'aiguille flottante et par l'araignée dans la Chine méridionale*, in *Toung Pao*, XV, 214-224.

[**62**] Martin [**22**, a] 27.

[**63**] Hashimoto [**9**] 92.

[**64**] Here we pass over several hypotheses, none of them supported by any evidence. Clarke, *Progress of maritime discovery*, London, 1803, I, vii, suggested that Noah employed the compass in the Ark. Kircher, *De arte magnetica*, Cologne, 1643, 19, mentions the statement of Rabbi Isaac Abarbanal that the Israelites knew and used the directive property of the magnet during their wanderings in the wilderness and in the construction of the tabernacle. Kircher also mentions other traditions of a like kind. With regard to the use of the compass in the Hedjaz from Cairo to Mecca, see Badger's edition of the *Travels of Ludovico di Vartema*, London, 1863, 31-32, with note. Ibn Majid, Vasco da Gama's Arab pilot, said that the nautical compass was invented by the prophet David, but was ascribed by some to Al-Hidr, the patron of the sea and protector of navigators. See Ferrand's commentary on MS. 2292, Bibliothèque Nationale, Paris, in *Ann. Géog.* XXXI, 289-307. Baily, *Histoire de l'astronomie ancienne*, Paris, 1781, 123, and Maurice, *History of Hindustan*, London, 1795-98, both state that the compass was known to the ancients, but give no evidence in support.

[**65**] Goropius,* *Opera Joan Goropii*, Antwerp, 1580, iii, 29.

[**66**] Pineda, *Salamonis commentarii*, Mayence, 1613, lib. iv, c. iv, 270.

[**67**] Fuller, *Miscellanea sacra*, London, 1617, bk. iv, 596.

[**68**] See Huetius, *Commentarium de navigationibus Salamonis*, in *Thesaurus antiquitatum sacrarum*, Venice, 1747, VII, ccci-cccii.

[**69**] Clarke [**64**] I, 397. Reviewed in *Phil. Mag.*, XVIII, 88.

[**70**] 2nd Chronicles, III, 6. See Thompson's note in Gilbert [**1**], 10.

[**71**] 2nd Chronicles, IX, 21.

[**72**] 2nd Chronicles, VIII, 18.

[**73**] 2nd Chronicles, VIII, 18.

[**74**] Proverbs, XXX, 18, 19, has a reference to "the way of a ship in the midst of the sea" as being one of four things which Solomon was unable to understand. There is here, however, no necessary implication that Solomon was referring to any special art or contrivance by which ships at sea were guided in their course.

[**75**] Hakewill, *An apologie or declaration of the power and providence of God*, 3rd ed. Oxford, 1635, lib. iii, c. 10, 323. He gives a list of references to earlier writers on the subject, the general trend of opinion being that the compass was not known in ancient times.

[**76**] Acosta, *Historia natural y moral de las Indias*, Seville, 1590. English trans., *The naturall and morall historie of the East and West Indies*, London, 1604, I, 37, 40, 47.

[**77**] Henricus Kippingius, *Antiquitates Romanorum*, Franquera, 1684, 833.

[**78**] Bochart, *Geographia sacra*, Caen, 1646, lib. i, c. 38.

[**79**] *Purchas, His pilgrims*, I, 8.

[**80**] Salverte, *Des sciences occultes*, Paris, 1829. English trans. London, 1846, I, 251-252. He quotes from Suidas, *Abaris;* Iamblichus, *Vita Pythagorae*, xxviii; Herodotus, IV, 36; and Diodorus Siculus, lib. iii, c. xi. Similar suggestions had been previously made by Clarke, [**64**] LI.

[**81**] Cooke, *An enquiry into the patriarchal and druidical religion*, London, 1755, 26-27.

[**82**] The passage relied on by Cooke is *Odyssey*, viii, 557-563.

[**83**] Buffon, *Supplément à l'histoire naturelle*, Paris, 1788, V, 269. Martin [**23**, a] 28, refers to this idea of Buffon's as "a hallucination."

[**84**] Mottelay, [**9**], who gives readings by different translators. But he seems to withdraw his support of Buffon's statement on p. 7.

[**85**] Falconet, *Mém. Acad. Inscr.*, IV, 613.

[**86**] In letter of Feb. 17, 1928, to present author

[**87**] Martin [**22**, a] 28.

[**88**] Buttmann, [**22**], who concluded the substance was talc.

[**89**] Albertus Magnus, *Opera*, Lyons, 1651, II, 243.

[**90**] Vincent de Beauvais, *Speculum naturale*, Strassburg, 1476, ii, lib. 9, c. 19. For bibliography, see Daunou, in *Histoire littéraire de la France*, XVIII, 449-519.

[**91**] The title is said to have been preserved by Diogenes Laertius, V, 26. The authenticity of this supposed work of Aristotle was examined very fully by Martin [**22**, a], 28-29. See also Klaproth, [**7**] 46-54, and Baron de Sacy, *Chrestomathie Arabe*, Paris, 1806, III, 447, 553, who has compared it with the *Traité des pierres* of Tei-fachi. Also Jourdain, *Recherches sur les traductions latines d'Aristote*, Paris, 1819, 350. I have not been able to find the corresponding passage in the edition of 1843.

For the controversy as to the meaning of the terms *zohron* and *aphron*, which occur in the passage quoted in [**89**] from Albertus Magnus, see Klaproth, [**7**] 50-51, who said these words were Arabic; and Lipenius, *Navigatio Salamonis Ophritica illustrata*, Halle, 1660, V, sect. iii, 36, who said they were neither Arabic, nor Greek, nor Hebrew, nor Chaldean.

With regard to the supposition of Rose, *Zs. Deutsch. Alterthum*, XVIII, 321-455, that Albertus Magnus and Vincent de Beauvais obtained their information from Arnold of Saxony, see Thorndike, *History of magic and experimental science*, London, 1923, II, 430, with references.

[**92**] Levinius Lemnius, *Occulta naturæ miracula*, Antwerp, 1564. English trans. by Brookes, *The secret miracles of nature*, London, 1659, 198-199.

[**93**] Plautus, *Mercator*, V, 2, and *Trinummus*, IV. 3.

[**94**] Gilbert [**1**], bk. II, ch. ii.

[**95**] Cabaeus, *Philosophia magnetica*, Ferrara, 1629.

[**96**] See Thompson's notes in Gilbert [**1**]. The passages from Plautus are quoted in full.

[**97**] Lestrange, *Seneca's morals by way of abstract*, London, 1699, part II, ch. ix, 195.

[**98**] See his translation of Pliny, t. XII, 484.

[**99**] Plutarch, *De Iside et Osiride*, ch. 62. See also Pliny, *Natural History*, bk. XXXVI, ch. xvi. Klaproth, [**7**] 12, refers to the passage in Plutarch, but the interpretation he puts upon it seems to be forced.

[**100**] Betham, *Etruria-Celtica*, London, 1842, I, 267-269.

[**101**] Dennis, *Cities and cemeteries of Etruria*, London, 1879, II, 105.

[**102**] "Tres adeo incertos caeca caligne soles
Erramus pelago; totidem sine sidere noctes." *Aeneid*, III.

"Clavumque affixus et haerens
Nusquam amittebat, oculosque sub astra tenebat." *Aeneid*, V.

The passage from Ovid is in *Tristia* (Bohn's ed., I, 327), "Ye Bears both Greater and the Less, which the one guides the Greek and the other the Sidonian ship." This is a reference to the fact that the Pole Star was known in classical times as the "Phenician Star."

[**103**] It may be convenient to collect together here all references to the papers of the learned scholar, Timoteo Bertelli, which have a bearing on the history of terrestrial magnetism. Taken as a whole, they form one of the most valuable pieces of bibliographical research of the last century. Their fullness and accuracy leave little room for addition by later commentators.

(*a*) Sopra Pietro Peregrino di Maricourt e la sua epistola De Magnete. *Bull. bibliogr. st. sci. mat. Fis.*, I, 1-32, 65-69, 101-139, 319-420.

(*b*) Intorno a due codoci Vaticani della Epistola De Magnete di Pietro Peregrino di Maricourt, ed alle prime osservazioni della declinazione magnetica. *Bull. bibliogr. st. sci. mat. Fis.*, IV, 303-331.

(*c*) Sull 'origine della parola calimita, uscita dagli Italiani ad esprimere la pietra magnete, l'ago e la bussola. *Moncalieri Oss. Bull.*, XI, 161-163, 177-178.

(*d*) Christoforo Colombo, scopritore della declinazione magnetica e della sua variazione nelle spazie. *Raccolta di documenti e studi pubblicata della Reale Commissione Columbiana nel quarto centario della scoperta di America*, Rome, 1892, Part IV, II.

(*e*) Riassunto di una memoria storica intorno alla scoperta della declinazione fatta da Christoforo Colombo nel 1492, *Atti Acc. Nuovi Lincei*, XLV, 97-100; *Moncalieri Oss. Bull.*, XII, 89-91; *U. S. Weath. Bur. Bull.*, XI, 486-492.

(*f* Studi storici intorno alla bussola nautica. *Mem. Acc. Nuovi Lincei*, IX, Part I, 77-178, and Part II, 131-219.

(*g*) Appunti storici intorno all' antica Rosa nautica Italiana, *Riv. Maritt.*, Nov. 1893.

(*h*) Sopra alcuni nuovi esemplari dell' Epistola di Pietro Peregrino di Maricourt De Magnete. *Atti Acc. Nuovi Lincei*, t. LI, 55-56.

(*i*) Di un supposto lavoro intorno alla bussola pubblicato da Filippo Pigafetta nel 1586, *Atti Acc. Nuovi Lincei*, LI, 73-77.

(*j*) Dell' origine della bussola e di alcune sue principali modificazioni, *Moncalieri Oss. Ann.*, I, 7-16.

(*k*) Appunti storici intorno all' uso topografico ed astronomico della bussola fatti anticamente in Italia, *Riv. geogr. ital.*, VII.

(*l*) Sopra un nuovo documento risguardante l'invenzione della bussola nautica, *Riv. fis.*, 1901.

(*m*) Sulle recenti controversie intorno all' origine della bussola nautica, *Riv. geogr. ital.*, IX.

(*n*) Nuova conferma che la declinazione magnetica era ignota ai Cinesi prima di Christoforo Colombo. Pavia, 1903.

(*o*) La leggenda di Flavio Gioja, inventore della Bussola, *Riv. geogr. ital.*, X.

(*p*) Della declinazione magnetica presso i Cinesi, *Boll. Soc. geogr. ital.*, III.

(*q*) Sopra un nuovo supposto primo inventore della bussola nautica, *Riv. geogr. ital.*, XI, fasc. ix.

An abstract of (*f*), (*m*), (*n*), (*o*), and (*p*) above was given by D. L. Hazard in *Terr. Mag.*, VIII, 179.

[**104**] Acosta [**76**] lib. i, c. 16.

[**105**] Dutens, *Recherches sur l'origine de la découverte*, Paris, 1766, II, 34. English trans. London, 1769, 206.

[**106**] Azuni [**30**] 24-29.

[**107**] "Lapis est cognomine Magnes . . . in marmore flammæ."

[**108**] Marcus Dods, *St. Augustine's City of God*, Edinburgh, 1871, II, 420, 457. At the Third Italian Geographical Congress, held at Florence in 1898, Col. Antonio Botto contributed a paper in which he maintained that St. Augustine's reference was to some form of compass. His paper,* *Contributo agli studi storici sull' origine della bussola nautica*, is printed in the *Acts* of the Congress. It was effectively answered by Bertelli in [**103**, m].

[**109**] Marcellus Empiricus, *De Medicamentis*, in *Medici antiqui omnes*, Venice, 1546, 89. Also in *Corpus medicorum latinorum*, Leipsic, 1916, V. ed. by Niedermann.

[**110**] For a full account of the maritime and commercial activities of the Phenicians, with numerous references to original sources, see Abbé Mignot's *Mémoires sur les Phéniciens* in *Mém. Acad. Inscr.*, particularly the 22nd *Mémoire* in XLII, 1-59. Also Ameilhon, *Histoire du commerce et de la navigation des Egyptiens sous le Règne des Ptolemies*, Paris, 1766. Details of sea routes used in these times are given. His conclusions confirm those of Campomanes, *Antiquidad maritima de la República de Carthago*, Madrid, 1756. Grote, *History of Greece*, ch. XVIII, gives an interesting account. More recent views on Phenician navigation, especially in relation to Homer's references on the point, are to be found in Victor Berard's elaborate work, *Les Phéniciens et l'Odyssée*, Paris, 1902-03, and in his shorter work, *Did Homer live?*, trans. by Rhys, London, 1931.

[**111**] See [**102**]. Pliny, *Natural History*, bk. VII, ch. 56, refers to this, and says that the Phenicians were the first to use the stars in navigation. Also Strabo, bk. I.

[**112**] Duncker, *History of antiquity* (Abbott's trans.), London, 1882, II, 293.

[**113**] For details as to the *Sanconiathon*, see Betham [**100**], and Kenrick, *Phenicia*, London, 1855, 330-336, where a translation of nearly all that remains is given.

[**114**] Betham [**100**] II, 8.

[**115**] Fuller [**67**] lib. iv, c. 19.

[**116**] Photius. See Kircher [**64**], 26.

[**117**] Gilbert [**1**] 4.

[**118**] Ptolemy, *Geographia*, I, 11; Strabo, *Geographia*, bk. III, c. v, 11. See also Clarke [**64**] Introd. lix.

[**119**] Herodotus, IV, ch. 49.

[**120**] Herodotus, IV, ch. 49.

[**121**] Osorius, *Histoire du Portugal*, Geneva, 1581.

[**122**] Cooke [**81**] 24.

[**123**] See Benjamin [**15**].

[**124**] See LaCouperie, *Western origin of early Chinese civilisation*, London, 1894, and Deveria, *Le fer et l'aimant dans l'ancienne Égypte*, Paris, 1870.

[**125**] This view was originally suggested by Klaproth [**7**], and has been quoted by many later writers. See Hirth [**9**] 134.

[**126** Ptolemy, *Geographia*, lib. I, c. vii.

[**127**] See]**44**].

[**128**] See Hirth and Rockhill, [**44**] 27.

[**129**] See [**46**].

[**130**] Pelliot, *Deux itinéraires de Chine en Inde*, Paris, 1904.

[**131**] See [**46**].

[**132**] Levi, *Journal Asiatique*, 1900.

[**133**] *Islands Landnámabók*, Copenhagen, 1774; also, 1900, I, ii, par. 7.

[**134**] See [**45**].

[**135**] Nevertheless, the claim has been made that the compass was in use in the eighth century in the seas round Java, though not, possibly, by Arabs. In Wilsen and Brummund's volume on the Buddhist temple at Boro-Boudour in Java, a description is given of certain stone carvings of ships. One of these shows small circular objects placed at bow and stern which, the editors believe, are intended to represent

compasses. These carvings are Malayan or Javanese, and are assigned to the eighth century. Their interpretation is a matter of considerable difficulty, and it is very far from clear that the objects—which are placed in a vertical, not a horizontal, plane—are intended to represent compasses. Had such been the case, some attempt would have been made to show the essential part of the instrument, the floating needle. But this is absent. See *Boro-Boudour dans l'Isle de Java* (Dutch Government publication), 1874.

[**136**] The reference here is to the work of Haskins, Thorndike, Wiedemann, and the editor of *Isis*.

[**137**] Koran, ch. VI.

[**138**] Thabet-ben-Corah, *De sideribus eorumque occasu ad artis nauticae usus accommodatis*; see Casiri, *Bibliotheca Arabo-Hispanico Escurialensis*, Madrid, 1760-70, I, 462. .

[**139**] Wiedemann, *Verh. D. Phys. Ges.*, 1907, 764-773.

[**140**] Ibn Khordadbeh, *Livre des routes et provinces*, trans. by Maynard; *J. Asiat.*, ser. 6, V. 281. Also given in *Bibliotheca geographorum Arabicorum*, ed. by Goeje, Leyden, 1899; and by Sprenger, *Abh. Deutsch. Morgen. Ges.*, III, No. 3. According to Kremer, *Culturgeschichte des Orients*, I, 269, Ibn Khordadbeh wrote between 854 and 874.

[**141**] For bibliography, see *Encyclopedia of Islam*, London, 1927, II, 913.

[**142**] In so far as he is quoted by Masoudi [**147**]. The original work has not been preserved.

[**143**] See Casiri [**138**], and Flugel, *Abhandlungen für die Kunde des Morgenlandes*, 1859, I. Also *Encyclopedia of Islam*, [**141**] II, 1019-1020.

[**144**] See *Encyclopedia of Islam*, [**141**] I, 611-612.

[**145**] See Pocock's* translation of the *Kitab-al-Fihrist*, Oxford, 1663.

]**146**] All that now remains of Ibn Muhalhil's travels has been collected by Schloezer, *Abu Dolif Ben Muhalhil de itinere Asiatico commentarius*, Berlin, 1845.

[**147**] Masoudi, *Prairies d'Or*, ed. by Maynard and de Courteille, Paris, 1861-77, I, 182, etc.

[**148**] Geber. Two persons there were of this name, and they have occasionally been confused together. See references given by Wiedemann, *Sitz. Phys-medicin. Soc. Erlangen*, XXXVI, 309-351.

[**149**] The evidence in question can be gathered from various sources. The Chinese are known to have been in communication with Ceylon in 428 A. D. See Levy, *J. Asiat.*, XV, 412, and also McCrindle, *Christian topography of Cosmas*, London, 1897, 365-366. Later data are referred to in [**46**]. See also Breitschneider, *On the knowledge possessed by the ancient Chinese of the Arabs and Arabian colonies*, London, 1871, 3-5, 11; Reinaud, *Mém. Acad. Inscr.*, 1849, 124; Yule, *Proc. R. Geogr. Soc.*, IV, 649-660; Richthofen, *China*, Berlin, 1877-83, I, 569; Heyd, *Histoire du commerce du Levant au moyen âge*, Leipsic, 1885, I, 28. For Chinese acquaintance with the Malabar coast, see Ferrand's review of the *Book of Duarte Barbosa* in *J. Asiat.*, 1924, 115. The annals of the Tang dynasty (620-907) speak of expeditions to *Molai*, i. e., Malabar. See Heyd, *v. s.*

[**150**] Stanislas Julien, *J. Asiat.*, ser. 4, X, 113, 120.

[**151**] Ferrand [**46**], Chavannes [**46**].

[**152**] *Travels of Ibn Batuta*, trans. by Lee, London, 1829, ch. XVIII, or Gibb's edition, London, 1929, 234, 235, 238.

[**153**] As to Aden, see the reference to Ibn-el-Wardi in Cordier's edition of Yule's *Cathay*, London, 1915, I, 87. As to Madagascar, Humboldt, *Cosmos*, London, 1849, II, 628.

[**154**] Masoudi [**147**] I, 303, 308.

[**155**] Maynard, *J. Asiat.*, ser. 7, I, 574-575, gives a quotation from Ibn Haukal regarding a wealthy Persian, Abou Bekr, whose ships sailed from Siraf to India, Zanzibar, and China in the year 355 A. H.

[**156**] See [**152**].

[**157**] For general reference on this part of the subject, the reader may consult Pliny [**102**], Strabo [**118**], Ameilhon [**110**], Vincent [**58**], Charlesworth, *Trade routes and commerce of the Roman Empire*, Cambridge, 1924, and Warmington, *Commerce between the Roman Empire and India*, Cambridge, 1928.

[**158**] Pliny, *Natural History*, Bostock and Riley's ed., VI, c. xxii.

[**159**] Hirth [**9**] 127. Reinaud, *Relations politiques de l'Empire Romain avec l'Asie Orientale*, Paris, 1863, 163.

[**160**] Elliot, *History of India*, London, 1867-77, I, 118; Reinaud, *Mém. Acad. Inscr.*, XVIII, 2, p. 79; Heyd [**149**] I, 33.

[**161**] Masoudi [**147**] I, 346. Khordadbeh [**140**] 294, 522.

[**162**] See [**150**].

[**163**] For details as to the canal connecting the Red Sea with the Nile and Mediterranean, see Heyd, [**149**] I, 40, where authorities are given.

[**164**] After the Arab victory over the Persians in 635-636, the Arabs built the town of Busrah in order to exclude the Persians from the Gulf trade to Oman and India. See St. Martin, *Recherches sur l'histoire et la géographie de la Mesene et de la Characene*, Paris, 1838, 54, where Modjmel-al-Tewarikh is quoted.

[**165**] Rawlinson, *Five great monarchies of the ancient Eastern World*, London, 1862-67, I, 544.

[**166**] Quatremere, *Journal des Savants*, 1846, 681.

[**167**] Malcolm, *History of Persia*, London, 1815, II; 63.

[**168**] Ferrand, *J. Asiat.*, 1924, 193-257. See also Reinaud, [**45**] I, Intro., xxxvi.

[**169**] Hasan, *History of Persian navigation*, London, 1928, 52.

[**170**] Reference may be made generally to Heyd [**149**] I.

[**171**] Reinaud [**45**] I, Intro., xxxvi.

[**172**] Alberuni, *India*, edited by Sachau, London, 1888, ch. XVIII.

[**173**] Jordanus,* Paris Geogr. Soc. ed., p. 62.

[**174**] Wilson, *Journal of the Asiatic Soc. of Great Britain*, V (1839), 5.

[**175**] Details of these treaties are given by Heyd, [**149**] I.

[**176**] From the statements of Strabo, bk. XVII, c. i, 14, we may gather that this was the case even in Roman times.

[**177**] Heyd [**149**] I.

[**178**] But see *Description de l'Afrique Septentrionale par El-Bekr*, trans. by Slane, *J. Asiat.*, ser. XIII, 73.

[**179**] The anecdote in which Awfi refers to the compass is that given in the serial number 1997 in the *Introduction to the Jawami of Al Awfi*, by Mohammed Nizamu'd Din, Gibb Memorial Series, N. S. No. VIII, London, 1929. For translation and other details see Wiedemann, [**139**] 765. From the former work, p. 12, it may be concluded that the probable date of the voyage during which Awfi saw the compass being used —most likely near the mouth of the Indus—was about 1220. Anecdotes 1996 and 2008 also refer to the lodestone. For biographical details, see *Encyclopedia of Islam*, [**141**] I, 517. Wustenfeld, *Die Wunder der Schöpfung*, Göttingen, 1848, has some comments.

[**180**] *Las siete partidas del Sabio Rey don Alfonso el X*, Madrid, 1829, I, 473. This compilation was begun in 1250 and completed in seven years. See Southey's *Omniana*, London, 1812, I, 210 (pagination wrong).

[**181**] The French title of Bailak's manuscript (Bibliothèque Nationale, MS. Arabe, No. 970) is *Trésor des marchands pour la connaissance des pierres*. See Klaproth [**7**] 57.

[**182**] Bertelli [**103, f**] ch. II.

[**183**] Renaudot [**45**] 142-145; Azuni [**30**]; Collina, *Considerazioni storiche sopra l'origine della bussola nauticæ nell' Europa e nell' Asia*, Faenza, 1740, 121, and his dissertation,* *De acus nauticæ inventore* in *Comment. Bonon.*, II, 382.

[**184**] Wiedemann, *Zs. Physik*, XXIV, 166-167, where references to original sources are given.

[**185**] See Caussin, *Notices et extraits des manuscrits de la Bibliothèque du Roi*, VII, 16.

[**186**] Stapleton and Azo, *Mem. Asiat. Soc. Bengal*, I, 531. Also Wiedemann [**139**].

[**187**] Alberuni [**172**].

[**188**] *Géographie d'Edrisi*, ed. by Jaubert, Paris, 1836.

[**189**] Fournier, [**55**] lib. XI, c. i. Klaproth, [**7**] 55, could find nothing that could bear this meaning. Further examination of Jaubert's edition confirms this conclusion.

[**190**] His correct name was Shems ed-din-Abou Abdullah Mohammad de Damas. The title of his work is *Nokhbet ed-dahr Fi Adjaib-il-Birr Wal-Bahr.* It was translated by Mehren,* *Manuel de la cosmographie du moyen âge*, Copenhagen, 1874-85.

[**191**] *Traité des instructions astronomiques arabes*, trans. by Sedillot, Paris, 1834.

[**192**] See Haskins, *Studies in the history of medieval science*, Cambridge, U. S. A., 1924, for bibliography and other details. Also Thorndike [**91**].

[**193**] Adelardus Bathonensis, *De eodem et diverso*, Willner's ed., Münster, 1903. See also references in [**192**]. One of the many curious mistakes made in the history of the subject will be found in Meig's book, *The story of the seaman*, Philadelphia and London, 1924, I, 265. He there states that Libri, *Histoire des sciences mathématiques*, Paris, 1838, II, 62, gives evidence showing that the first mention of the compass in European literature may be brought within narrow limits, viz., 1117-1130. But Libri said nothing of the kind. What he did say was that Adelard of Bath was *not* acquainted with the polarity of the magnet, and shows that Adelard's writings on the matter could be dated between 1117 and 1130.

[**194**] See references in [**192**].

[**195**] See references in [**192**]

[**196**] The passage referred to is on p. 236 of the Paris Geographical Society's edition of *Marco Polo.* Referring to the number of islands in the Indian Ocean, he gives their supposed number, "selone qe moister le conpas et la scriture de sajas mariner qe uzent en cel mer de Yndie."

Beazley, *Dawn of modern geography*, London, 1897-1906, III, 150, renders this, "according to the writings and compass-reckonings of experienced seamen who navigated that sea." This would imply that Marco Polo believed that the compass was in use in the Indian Ocean about the middle of the thirteenth century. But I am informed on high authority that in thirteenth century French, the word "conpas" did not mean "compass," the nautical instrument. Hence Beazley's rendering cannot be accepted. In his edition of Yule's *Marco Polo*, II, 424, Cordier confirms Yule's translation, "according to the charts and documents of experienced mariners who navigate that Indian sea." Olivieri's edition, Bari, 1912, has much the same rendering.

[**197**] This suggestion of Gilbert's, [**1**], Bk. I, ch. i, found wide currency, chiefly by repetition unaccompanied by examination of the evidence. The first to oppose it was Huet, *History of the commerce and navigation of the ancients*, London, 1717, 26. For reference to the planisphere supposed to have been brought from China by Marco Polo, and preserved at Venice, see Azuni, [**30**] 88, and Klaproth, [**7**] 61-62. In his edition of Gilbert's *De Magnete*, London, 1893, Mottelay gives a list, by no means exhaustive, of authors who had written on the compass before Marco Polo had returned from China.

[**198**] The reference here is to Neckam [**232**], [**233**].

[**199**] Ibn Batuta [**152**].

[**200**] Ramusio, *Navigazione e viaggi*, Venice, 1588, I, fol. 379.

[**201**] The original is in the Bibliotheca Marciana, Venice. See Azurara, *Chronicle of the discovery and conquest of Guinea*, trans. by Beazley and Prestage, London, 1896-99. Also, Zurla, *Il mappamondo di Fra Mauro*, Venice, 1806, 52, 128.

[**202**] *The three voyages of Vasco da Gama*, Hakluyt Soc. London, 1869, XV, 138. Also, *Journal of the first voyage of Vasco da Gama*, ed. by Ravenstein, Hakluyt Soc London, 1898, 26. The former is based on Correa's *Landas da India*, which contained many errors. The latter is a translation of the *Roteiro*, written by some person unknown who accompanied Vasco da Gama on the first voyage. In this connection, see three papers by Ferrand, (*a*) *Ann. géogr.*, XXXI, 289-307; (*b*) XXXII, 298-312; (*c*) *J. Asiat.*, 1924, 193-257. The statement that Vasco da Gama's pilots used the compass has been disputed. See Ramusio [**200**] I, fol. 379; Barrow, [**60**] 355; Renaudot,* *Dissertation sur les sciences des Chinois*, 288-289. But Ferrand's papers settle the matter definitely.

[**203**] Varthema [**22**] 31, 32 (notes), 248, with comments in Introduction.

[**204**] See [**202**].

[**205**] Riccioli, *Géographie et hydrographie*, Bologna, 1661, lib. x, c. 18.

[**206**] Salverte [**80**] 252. The only authority he quotes is *Nouvelles annales des voyages*, XVII, 414.

[**207**] Adam of Bremen, *Gesta Hammaburgensis Ecclesia Pontificum*, in Pertz, *Monumenta Germaniae.*

[208] Benjamin [**15**] 140-141.

[209] See Salverte's authority [**206**].

[210] Hennig, *Verh. Deutsch. Naturforscher*, 1912, 95.

[211] Details and references in Heyd [**149**] I, 57-58.

[212] See Heyd [**149**] I, 59-60.

[213] Posteraro's paper, *Origine italiana della bussola nautica inventata dal Veronese Salamone Ireneo Pacifico*, was communicated to the Fifth Italian Geographical Congress in 1904. See *Geogr. J.*, London, XXV, 334-335.

[214] Bertelli [**103**, **q**].

[215] *Histoire littéraire de la France*, VI, 609-610. The best account of Sylvester II is that of Picavet, *Gerbert, Un pape philosophe*, Paris, 1897.

[216] *Ditmari Chronicon*, 1580 edition, lib. vi, 83. Also given by Bouquet *Rerum Gallicarum Scriptores*, X, 131. The passage is as follows: "In Magdeburg, horologium fecit, illud recte constituens, considerata per fistulam quadam stella, nautarum duce." The first to suggest that the last two words alluded to a compass or the magnetic needle was Majolus, *Dies Caniculares*, Mayence, 1610, 566-567. He was followed by Kircher, *Ars Magnetica*, 1631, 27, who credited Gerbert with a knowledge of the directive property.

[217] Ameilhon, *Mém. Acad. Inscr.*, XLII, 504, note. Gerbert's letter to Constantine is given by Mabillon, *Analecta Vetera*, Paris, 1723, 103.

[218] Trombelli, *Comment. Acad. Sci. Bonon.*, XI, iii, 350.

[219] Montucla, *Histoire des mathématiques*, Paris, 1799, II, 501.

[220] Baldelli Boni, *Storia della relazioni vicendevoli dell 'Europa e dell 'Asia*, Florence, 1827, I, 333.

[221] Gibbon, *Decline and fall of the Roman Empire*, ch.. LVI, note. The poem of Appulus is reprinted in *Monumenta Germaniae Historica*, Wilman's ed., 1843, IX, iii, 478. Also in Muratori, *Rerum Italicarum Scriptores*, Milan, 1724, V. 267. The position of Amalphi as a centre having extensive commercial relations with the East might possibly justify the expectation that it, if any, would be the place at, or in connection with, which the compass might have been invented or improved. See the *History* of William, Archbishop of Tyre, in *Gesta Dei per Francos*, Honnoniae, 1611, 933, and the remarks of Bertelli [**103**, **f**]. Also Gibbon, *History of the Crusades;* Adler's edition of the *Itinerary of Benjamin of Tudela;* London, 1907, 9, 76; Scherer, *Histoire du commerce*, Paris, 1857, I, 285-286. Most of the original sources are summarized in Heyd [**149**] I.

[222] Hansteen, *Magazin for Naturvidenskaberne*, 1, 2.

[223] *Islands Landnámabók*, Copenhagen, 1774; also 1900, I, ii, par. 7. Bibliographical and other information is supplied by Mobius, *Ares Islanderbuch*, Leipsic, 1869, Introduction.

[224] Kamtz, *J. Chem. Phys.*, XV, 61, note.

[225] Klaproth [**7**] 39. In spite of this, the supposed reference in the *Islands Landnámabók* has been cited in recent times as the earliest mention of the compass in European literature. For example, Brockhaus, *Conversations-Lexicon*, Leipsic, 1902, X, 524-526.

[226] Beamish, *Discovery of America*, London, 1841, 53. Macpherson, *Annals of Commerce*, London, 1805, I, 261.

[227] The relevant passage is given by Wright, *A volume of vocabularies*, 1882, p. xviii. A translation is given by Benjamin [**15**] 149.

[228] In the preface to his *Lais Inédits*, Paris, 1836.

[229] *Bulletin du Bibliophile*, Sept., 1836.

[230] Wright [**227**]. It is, of course, still possible to maintain that Guyot copied the passage in *La Bible* from William the Clerk, and this rather perverse supposition has been put forward by Benjamin, [**15**] 153. See also Wright, *Biographia Britannica*, London, 1846, II, 426.

[231] According to Cave, *Scriptorum ecclesiasticorum historia literaria*, London, 1688, Neckam died in 1227, but this is a mistake. Practically all that is known of Neckam's life will be found in the *Dictionary of national biography*, with full list of sources.

[232] Neckam's *De Utensilibus* was first printed by Wright in [**227**], I, 96-119. Wright also referred to Neckam in his *Biographia* [**230**], II, 449-459, and in *Popular treatises on science during the Middle Ages*, London, 1841. Copies of the MS. are in

the British Museum (MS. Cotton, Titus D, xx) and the Bibliothèque Nationale, Paris (MS. Latin, No. 217, and 7679). In his preface, Wright calls attention to a curious point in *De Utensilibus.* Neckam states that when the needle, after magnetisation, ceased moving, it pointed towards the east, *donec cuspis acus respiciat orientem.* Wright offers an explanation for this mistake, but it does not seem to be altogether satisfactory. The matter is also referred to by Bertelli, [**103**, **f**] 144-145; D'Avezac, *Bull. soc. geogr.*, XV, 176-177; and Schück, *Ausland* (Stuttgart), 1892, 590. Whatever the explanation may be, the corresponding passage in *De Rerum Naturis* puts the matter correctly. See also Chappell, *Nature*, June 15, 1876, 147.

[**233**] *De Rerum Naturis* has been printed in the Rolls Series, vol. 34, with a preface by Wright, and also in his *Vocabularies*, [**227**] I, 114. Copies of the MS. are in the libraries of Magdalen College and St. John's College, Oxford, and in the British Museum, MS. Reg. 129, XI, fol. 53v.

[**234**] With regard to the date of composition of the *De Utensilibus*, Wright gives reasons for assigning it to the twelfth century. Neckam returned to his post as schoolmaster at Dunstable in 1187, and his book was evidently intended for use as a school book. He only remained there a year, and it is probable that during that year he prepared the work for the use of his pupils. Mottelay [**9**] puts Neckam under the year 1207; while Busch, *Ann. Hydrogr.*, 1926, 120-126, 169-174, puts him at 1200. In neither case is any reason given in support.

The facts with regard to Neckam's contribution to the history of the compass have been known for a considerable time. It is therefore surprising that error regarding them should still persist. For example, see an article by Curtiss, *Account of the rise of nagivation*, in *Pop. Astr.*, XXVI, April, 1918, reprinted in *Smithsonian Report*, 1918, 127-138, in which, among other mistakes, the author states that "the compass was introduced generally into Europe about 1400 A. D."

[**235**] The most complete edition of Guyot's works is *Les Oeuvres de Guiot de Provins, Poète Lyrique et Satyrique*, edited by Orr, Manchester, 1915. It is a most exhaustive recension of all Guyot's poems, together with full references to original sources and commentaries. The passage relating to the compass is p. 29-30, lines 632-654.

[**236**] Orr [**235**] xx. M. Paulin Paris had dated it 1190, and this was repeated by Fleuriais, *Annu. Bur. longit.*, 1894, B1-B37; Meyer, *Conversations-Lexicon*, Leipsic, 1895, X, 424; Brockhaus, *Conversations-Lexicon*, Leipsic, 1902, X, 524-528; Sedgwick and Tyler, [**47**]. The *Nouveau Larousse Illustré* gave it as 1190. But Orr's argument disposes of the matter quite conclusively.

[**237**] Pasquier, *Recherches de France*, 1st ed. Paris, 1650, ch. xxii, 220-221, 405, 603. See Orr [**235**] xxx. The mistake arose through Pasquier using a manuscript in which *La Bible* of Guyot was followed by that of De Bercy. Misled by the resemblance between the two, and by the fact that while De Bercy is named in his own poem, Guyot is not named in his, Pasquier attributed both to De Bercy. Fauchet, *Recueil de l'origine de la langue et poésie françaises*, Paris, 1581, 88-90, used the same manuscript but did not make the same mistake.

[**238**] Barbazan, *L'Ordene de Chevalerie*, Paris, 1759, 100, 203.

[**239**] Comte de Caylus, *Hist. Acad. Inscr.* XXI, 191-197.

[**240**] Schück, *Arch. Gesch. Natw. Techn.*, IV, 41, held to this opinion after consideration of the evidence, and it has also been adopted by Nippoldt, *Erdmagnetismus, Erdstrom und Polarlicht*, Berlin, 1921, 17. Apart from the explanation given above as to the origin of the belief, another objection to the identification of Guyot with De Bercy is that the latter wrote much later than the former. It is admitted that De Bercy's date is only approximate.

[**241**] Pasquier [**237**]. Azuni [**30**] 105. See also Fauchet [**237**], and Orr [**235**] xxxi. An example of the error will be found in Brockhaus [**225**], 1885 ed., X, 447.

[**242**] First edited and published by Gasser,* *Maricurtensis de magnete*, Augsburg, 1558. This edition was plagiarised by Taisnier in his *Opusculum perpetua memoria dignissium de natura magnetis*, Cologne, 1562; English trans. by Eden, London, 1579. See Bosman, *Revue des questions scientifiques*, October, 1921. Translation of the original MS. has been found difficult, but it has been given by Libri, *Histoire des sciences mathématiques*, Paris, 1838, II, 487; S. P. Thompson, Chiswick Press, London, 1902; Arnold, Troy, U. S. A. 1904 and Hellmann, *Zs. Erdk.*, XXXII, Heft 2, also published separately, Berlin, 1897, and a French translation in *Bul. Soc. belge. Astr.*, II. A version of the letter was also published in *Mém. Soc. géogr., Paris*, VII. A good summary is given by Mottelay, [**9**] 47-53, who gives other references.

[**243**] Bertelli [**103**, a, b, h]. For bibliographical notes in addition to those of Bertelli, see Hellmann's *Neudrücke von Schriften und Karten über Meteorologie und Erdmagnetismus*, No. 4, Berlin, 1895. See also Schlund, *Archivium franciscanum historicum*, IV, 436-455, 635-643; V, 22-40.

[**244**] See Mottelay [**9**].

[**245**] Peregrinus was anticipated by Neckam with regard to this point. As far as the present writer has been able to ascertain, most of the statements that Peregrinus introduced the pivoted compass have been derived from Benjamin, [**15**] 185.

[**246**] Jacques de Vitry, *Historia Orientalis seu Hierosolymitana*. For bibliography, see *Bibliotheca geographica Palestinae*, edited by Rohricht, Berlin, 1890, 48-50.

[**247**] Thomas of Cantimpre, *De natura rerum*. For bibliography and references, see Thorndike, [**91**] ch. LIII, and 396-398.

[**248**] Thorndike [**91**].

[**249**] Riccioli [**203**] 473.

[**250**] Haskins [**192**]. Two passages bearing on the magnet are given, with references to original sources. See also *Isis*, IV, 250-275.

[**251**] Klaproth [**7**] 53.

[**252**] See [**90**].

[**253**] Pliny, *Natural History*, Bostock and Riley's ed. VI, 355.

[**254**] Isidorus Hispaliensis, *Opera Omnia*, ed. by Arevale, Rome, 1797-1803. See the *Origines*, xvi, 4. Also his *De natura rerum*, ed. by Hecker, Berlin, 1857. Compare Ebert, *Geschichte der Literatur des Mittelalters im Abendlande*, I, 555, and Pouchet, *Histoire des sciences naturelles au Moyen Âge*, Paris, 1845.

[**255**] Michael Constantine Psellus,* *De lapidum virtutibus*, Toulouse, 1615.

[**256**] See *Histoire littéraire de la France*, XXIII, 576, 831. For translation of his verses, see Mottelay [**9**] 33.

[**257**] See Ginguene, *Histoire littéraire de l'Italie*, I, 413. Translation is given in Mottelay [**9**] 44, and by Longfellow, *Poets and poetry of Europe*, p. 511.

[**258**] Schück, *Mitt. Gesch. Med. Natw.*, XIII, 333. In the same paper Schück refers to another early mention of the compass. It is contained in a poem by Reinfrit von Bruneswic, reprinted in *Bibl. lit. Ver.*, *Stuttgart*, Wien, 1869. Reinfrit wrote about the end of the 13th or the beginning of the 14th century.

[**259**] Torfaeus, *Historia rerum Norvegicarum*, Copenhagen, 1711, IV, 345.

[**260**] Capmany, *Memorias historicas sobre la marina, comercio*, etc., Madrid, 1792.

[**261**] Brunetto Latini, *Li livres dou Tresor*, ed. by Chabaille, Paris, 1863, 147 The mention by Brunetto Latini of the polar properties of the magnet anticipates the letter of Petrus Peregrinus by about nine years. This is frequently forgotten by commentators.

[**262**] *Paradise*, canto xii, line 26.

[**263**] Klaproth [**7**] 46.

[**264**] The following is, perhaps, a sufficient list of examples: Major, *Life of Prince Henry the Navigator*, London, 1868, 58; Schück, *Arch. Gesch. Natw. Techn.*, III, 127-139; Gunther, *Early science in Oxford*, Oxford, 1921, I, 298; Benjamin [**15**] 162; *Volpicelli* [**30**] 209; Knight [**11**] 1397; Mottelay [**9**] 59; and Meigs, *Story of the seaman*, Philadelphia, 1924, 268.

[**265**] *Monthly Magazine or British Register*, London, 1802, XIII, 449.

[**266**] *Monthly Magazine*, XIV, Part II, 391. Klaproth's omission can only be accounted for by supposing that he had never seen the originals. Attention was first called to the acknowledgment of the forgery by Davies [**15**] 307-308, but this has been overlooked by most historians of the subject. It came near rediscovery when D'Avezac, *Bull. Soc. géogr.*, Paris, XV, 179, pointed out the suspicious circumstance that a portion, at least, of the supposed letter of Brunetto Latini was simply a prose version of a passage in *La Bible* of Guyot. Thirty-five years later it was again referred to by O'Neill, *The night of the Gods*, London, 1893, I, with the remark that "no one seems to have detected this." A still more curious feature is that Klaproth refers to the author of the letters as "an English scholar." As a matter of fact, his name was Dupré.

[**267**] Bacon, *Opus Minus*, Brewer's ed., London, 1859, 383-384.

[**268**] Barbour's *Bruce*, bk. V, lines 19-23:
"Thai rowit fast with all thar micht
Till that apon thame fell the nycht
That it wox myrk on gret maner
Swa that thai nist nocht quhar thai wer
For thai na needil had na stane."

[**269**] *Principal facts of the Earth's magnetism* [**59**] 20.

[**270**] Bertelli [**103**, f, j, m, o].

[**271**] *Blondi Flavii Forlivensis in Italia Illustrata*, Turin, 1527, 152.

[**272**] Torello da Fano, *Digestorum seu Pandectorum ex Florentinis pandectis repraesentatis*, Florence, 1553.

[**273**] Mazella, *Descrittione del regno di Napoli*, Naples, 1586, 41.

[**274**] Polydore Vergil, *De inventoribus rerum*, Venice, 1507, lxxxiA.

[**275**] Baptista Pio,* *In Caium Lucretium poetam commentarii*, Bonon., 1511, ccvii.

[**276**] Giraldus,* *De re nautica Caelii Calcagnini commentatio.*

[**277**] Collenuccio, *Compendio dell' historia del regno di Napoli*, Venice, 1539, lib. I, 16B, 17A.

[**278**] Giraldus, *Libellus de re nautica*, Basel, 1580.

[**279**] Lopez, *Historia general de las Indias*, in the *Bibliotheca de autores españoles historiadores primitivos de India*, ed. by de Vedia, Madrid, 1852, I, 161.

[**280**] Cardan, *De Subtilitate*, Norimberg, 1550, 386.

[**281**] Belon, *Singularium et memorabilium observationum*, Paris, 1553, ch. xvi.

[**282**] Gasser, in preface to his edition of Peregrinus [**242**].

[**283**] Lemnius, [**92**] 1564 ed., lib. iii, cap. iii, 302.

[**284**] Bartolomeo da Fano, in *Nuova seconda Solva rinnovato di varia lettione*, Venice, 1626, ch. xxxvi.

[**285**] Aldrovandi, *Musaeum metallicum*, Bonon. 1648, 567.

[**286**] The references immediately above show how soon and how widely the statement of Giraldus was repeated. In addition, see the uncompromising statements of Brechmann in *Thesaurus antiquitatum et historiarum Italiae, Neapolis, et Magnae Graeciae*, Leyden, 1723, IX, c. xxii. He stated, quite erroneously, that as evidence of the Amalphian origin of the compass, a representation of the instrument is incorporated in the arms of the town of Amalphi. This has been frequently repeated; its latest appearance being in Barker's *The compass, historical, theoretical, practical*, London, 1892. But it has been fully investigated and disposed of by Bertelli [**103, f**]. See also the references given by Brachmann, to which many more of like tenor might be added. As an example of the confusion produced, see Birkenmeyer, *Le curieux antiquaire*, London, 1729, I, 318, who, speaking of Amalfi, says, "L'on dit que Flavio Blondi inventa ici la Boussole."

[**287**] Mazella [273].

[**288**] Ortelio, *Theatro del mondo*, Antwerp, 1612.

[**289**] Bertelli [**103**, o]. See Casanova,* *Degli studi storici di T. Bertelli intorno alla bussola nautica*, (Rome?) 1895.

[**290**] Grimaldi, *Saggi di dissertatione dell' Acad. Etrusca di Cortona*, 1741, III, 915.

[**291**] Venanson, *De l'invention de la boussole nautique*, Naples, 1808. He is referred to as "Vellanson" by Benjamin [**15**] 104.

[**292**] Briet, *Annales mundi*, Venice, 1693, VI.

[**293**] Voltaire, *Essai sur les moeurs*, 1819, III, c, CXLI.

[**294**] Botto, see [**103**, m]; Proto-Pisani, *Sull' origine della bussola.* Portici, 1901; Porena, *Nuova antologia*, November 1902.

[**295**] Signorelli, *Vicende della coltura nelle due Sicilie*, Naples, 1810, II, 475.

[**296**] Camera, *Istoria di Amalfi*, Naples, 1836, 231, and *Memorie storico-diplomatiche*, Salerno, 1876, cap. xxxi, 453.

[**297**] Fiucati, *Il magnete, la calamita, e la bussola, Rome*, 1878. Reference may also be made to a paper by Sevillot, in *Bull. Bibliogr. st. sc. mat. fis.*, I, 161-166.

[**298**] Poggendorff, *Geschichte der Physik*, Leipsic, 1879, 98-111.

[**299**] Voltaire [**293**] III, 251.

[**300**] Nicholas, *History of the Royal Navy*, London, 1847, II, 180.

[**301**] Capmany, [**260**].

[**302**] Schück, *Der Kompass*, Hamburg, 1911.

A NEW THEORY OF MAGNETIC STORMS*

By S. Chapman and V. C. A. Ferraro

PART I—THE INITIAL PHASE (Continued)

8—*The conductivity, thickness, and density of the current-bearing layer*

8·1—In the absence of a magnetic field, the conductivity σ of a rare gas composed of equal numbers of electrons and positive ions (of masses m_e, m_i) is due almost wholly to the electrons. The electronic conductivity σ_e will be denoted by $(\sigma_e)_0$ when there is no field: its value is approximately 1.6×10^{-9} e.m.u., independent of the number N of electrons or ions, over a wide range of N (§1.61). The corresponding ionic conductivity $(\sigma_i)_0$ is $(m_e/m_i)\ (\sigma_e)_0$.

A magnetic field H reduces σ_e and σ_i in the approximate ratio $R^2/(R^2+l^2)$, where $R=mv/eH$, and l, the mean free-path, is proportional to $1/N\sqrt{m}$; here R, v, l, and m should all have the appropriate suffix e or i. In a rare gas at temperature T, $\frac{1}{2}m\,v^2=\frac{3}{2}\,kT$, so that $R_i/R_e=(m_i/m_e)^{1/2}$. Thus

$$\sigma=\sigma_e+\sigma_i=(\sigma_e)_0\left(\frac{R_e^2}{R_e^2+l_e^2}+\frac{m_e}{m_i}\cdot\frac{R_i^2}{R_i^2+l_i^2}\right) \tag{47}$$

$$=(\sigma_e)_0\frac{1}{1+l_e^2/R_e^2}\left(1+\frac{m_e}{m_i}\cdot\frac{1+l_e^2/R_e^2}{1+l_i^2/R_i^2}\right)$$

$$=(\sigma_e)_0\frac{1}{1+\alpha^2H^2}\left(1+\frac{m_e}{m_i}\cdot\frac{1+\alpha^2H^2}{1+(m_e/m_i)^2\alpha^2H^2}\right)$$

where

$$\alpha=l_e/R_eH=el_e/m_ev_e, \tag{48}$$

which is equal to $7\times 10^{10}/N$ when $T=6000°$.

For values of H from zero to about H_i, where $\alpha^2H_i^2=m_i/m_e$, σ_e exceeds σ_i; as H increases up to H_i, σ decreases from approximately $(\sigma_e)_0$ to $2\ (m_e/m_i)\ (\sigma_e)_0$. When $H>H_i$, $\sigma_i>\sigma_e$; for values of H such that α^2H^2 is large compared with m_i/m_e

$$\sigma\doteq\frac{m_i}{m_e}\cdot\frac{(\sigma_e)_0}{\alpha^2H^2} \tag{49}$$

If the atomic weight of the ions is A, so that $m_i=Am_H$, where m_H denotes the mass of a hydrogen atom, (49) is equivalent to

$$\sigma\doteq 6{\cdot}4\times 10^{-28}A\,N^2/H^2 \tag{50}$$

for large values of H, when $T=6000°$. At a point in the Earth's equatorial plane, at Z Earth-radii from the Earth's center, $H=0{\cdot}3\ Z^{-3}$, so that

$$\sigma\doteq 7{\cdot}0\times 10^{-27}\,AN^2Z^6 \tag{51}$$

*Continued from this Journal, 36, 77-97 and 171-186 (1931).

this holds for values of H large compared with H_i, the value of which is

(52) $$6{\cdot}3\times10^{-10}\,N\sqrt{A}$$

8.2—The bearing of these results on the shielding of the interior of the stream from the Earth's field will now be considered. In particular, we will investigate the thickness of the current-bearing layer in which the field is reduced to a fraction f of the external value. For simplicity we shall suppose that the stream has an infinite plane boundary, and extends throughout space on the side of the plane further from the Earth; thus we neglect the distortion of the surface as the stream approaches the Earth (with the velocity w, normal to the surface). The variation of the induced currents at a depth d within the conductor can be inferred from a development of the theory of thin plane current-sheets, using the method of images. The expressions derived for the magnetic potential inside and outside the conductor are, however, too complicated for convenient use, and an approximate treatment is more suitable. But the method of images makes it clear that, for depths d that are small compared with the distance (Za) of the Earth from the surface of the conductor, the ratio (f) of the intensity of the field at depth d, to the external field, will be approximately the same as would be produced by a *thin* current-sheet of conductivity σd per unit area. Hence, by §7·1, $f=1/(1+2\pi\sigma wd)$, and when $2\pi\sigma wd$ is large (provided that d/Za is still small), $f\doteq1/2\pi\sigma wd$.

The following Table gives the values of d corresponding to various values of f and of σ, when $w=10^8$ cm/sec. The values of σ are (a), $(\sigma_e)_0$ or $1{\cdot}6\times10^{-9}$, and $(m_e/m_i)\ (\sigma_e)_0$ for the two cases (b) for $A=1$, (c) for $A=40$. These two values (9×10^{-13}, 2×10^{-14}) correspond to the transverse conductivity in a gas in which the ions are respectively hydrogen atoms and calcium atoms, in the presence of a magnetic field (slightly greater than H_i, in §8.1) strong enough to reduce the electronic transverse conductivity to a value slightly below the full ionic conductivity $(\sigma_i)_0$.

Case	Depth	Ratio f							
		0.75	0.50	0.30	0.20	0.15	0.10	0.05	0.01
(a)	d in cm	0.33	1.0	2.3	4.0	6.3	9.0	19.0	99
(b)	d in m	6.1	18.4	40	74	113	166	351	1815
(c)	d in km	0.25	0.74	1.6	2.9	4.5	6.6	14	73

For values of f less than 0.01, d is approximately $1/f$ cm when $\sigma=(\sigma_e)_0$, and $0.018/f$ km, $0.0074/f$ km, for $\sigma=\sigma_i$ in the case of H and Ca ions, respectively. Thus the external field is reduced to one per cent of its value by a layer of gas one metre thick, if the magnetic field is absent (or so weak as not seriously to impair the freedom of the electrons to conduct); if, however, the ions only are free to conduct, the layer is at least of thickness 1.8 km, and may be 73 km, according to the nature of the ions. If the magnetic field is strong enough to reduce the ionic conduction, the thickness will be still greater; but the remarkable thing about all these estimates is the thinness of the layer com-

pared with the dimensions of the stream, or even of the Earth. The estimated thickness may indeed be less than the mean free-path of the electrons (or ions, according to the nature of the conduction), and in this case the electrons will conduct almost freely, provided that $R_e > l_e$; but so long as d is not less than the mean free-path, the above estimates, for the assumed conductivities, will be of the right order of magnitude.

If w be greater or less than the assumed value 10^8 cm/sec., the above estimates of d must be reduced or increased by the factor $10^8/w$.

8.3—The discussion in §7.9 suggests that the current-bearing surface layer of a stream begins to be of importance in relation to magnetic storms when Z lies between 10 and 5, corresponding to $H=3\times 10^{-4}$ and $2{\cdot}4\times 10^{-3}$; §7·9 also suggests that in storms having a sudden commencement, the value of N (N_0, say) for the stream, before this enters the Earth's field (e. g. at a distance $100a$ from the Earth) is about 1000 or more. The values of N mentioned in §8·1 refer to the actual density at any point, and the density in the current-bearing layer, which is of special interest, will become much greater than N_0 as Z decreases, owing to the retardation of the surface-layer, and the consequent inpouring of less retarded matter from behind.

If this increase of density did not occur, and N remained constant, σ would attain very low values near the Earth, and the requisite thickness d of the current-bearing layer, for shielding of the interior of the stream, would become very great. For example, suppose $A=40$ (as for a calcium stream) and $N=N_0=1000$; then $H_t=4\times 10^{-6}$, which is small compared with H at $Z=10$ or less. Hence σ for $Z\leq 10$ is given by (51), and at $Z=10$, $Z=5$, its values are respectively $2{\cdot}8\times 10^{-13}$ and $4{\cdot}4\times 10^{-15}$; the second of these is one-twentieth of the value of σ considered in the last row of the above Table, so that the values of d in this row, for a calcium stream of density $N=1000$ at $Z=5$, need to be increased twentyfold. For $f=0{\cdot}1$ this gives $d=1500$ km, which is still small compared with the distance Za, which for $Z=5$ is about 34,000 km. But as Z decreases below 5, σ diminishes rapidly, and also w; the necessary increase of d (in the ratio $1/\sigma w$), as above calculated, soon renders it larger than Za; the current-bearing layer can then no longer be treated as thin, and a more accurate calculation of the shielding and of the magnetic field of the currents in the layer, would show that they are reduced by the thickening of the layer.* But the more important correction to the above illustrative calculations is that obtained by taking account of the changing *density* of the layer.

8·4—We next try to obtain some notion of the variation of density in the current-bearing layer as this enters the Earth's field. As before, we shall confine our attention to the vertex O of the hollow formed by the stream-surface, and to the part of the stream behind O, along the line COS joining the Earth's center C and the sun S. As in §7·8, C is taken as the origin, and COS as the negative z-axis. The coordinates of O are $(0, 0, z_0)$, where z_0 is negative. The intensity H_0 of the Earth's field at O is

$$H_a\ (a/z_0)^3 \tag{54}$$

where $H_a=0{\cdot}3$; the direction of H is taken as that of the x-axis.

* For a given magnetic intensity near the Earth due to the currents in the layer, the surface must be nearer the Earth, the thicker the layer.

The currents induced in the stream at O will flow in the y-direction. Let i be the current-intensity at the point $(0, 0, z)$ inside the stream (so that $-z>-z_0$), and let ρ be the density, and F the electromagnetic mechanical force per unit volume, at this point. Then if H be the magnetic intensity there,

(55) $$F=iH$$

Further, neglecting displacement currents, and neglecting also the small curvature of the magnetic lines of force

(56) $$i=(1/4\pi)\,\partial H/\partial z$$

Since the force F opposes the motion, the equation of motion of the volume-element which at time t is at z is

(57) $$\rho\ddot{z}=-F=-iH=-(1/8\pi)\,\partial H^2/\partial z$$

On the left z is a Lagrangian coordinate; if z_∞ denotes its value when $t=0$ (this instant being chosen as one when O is very far from the Earth), and ρ_∞ denotes the corresponding value of ρ, we have the Lagrangian equation of continuity

(58) $$\rho=\rho_\infty(\partial z_\infty/\partial z)$$

The point z is at depth $d=z_0-z$ (taking d as positive) within the stream. When z_0 is large, so that the stream is only slightly affected by the Earth's field, the reduction of H at depth d, that is, the value of f or H/H_0, is approximately given by (cf. §8.2) $1/(1+2\pi\sigma wd)$, where σ and w are the conductivity and velocity ($\dot{z}$) of the stream at the point z. In this case $\partial H^2/\partial z=-\partial H^2/\partial d=4\pi\sigma wH_0^2 f^3$, and

(59) $$\rho\ddot{z}=-(1/2)\sigma wH_0^2 f^3$$

since σw may be treated as constant. Taking $z=z_0$, when $f=1$, this gives

(60) $$\rho_0\ddot{z}_0=-(1/2)\sigma wH_0^2$$

where ρ_0 is the value of ρ at z_0. Hence

(61) $$\rho\ddot{z}=\rho_0\ddot{z}_0 f^3$$

This is of the form

(62) $$\rho\ddot{z}=F(t)P(z-z_0)$$

where

(63) $$\rho_0\ddot{z}_0=F(t),\ P(z-z_0)=f^3=1/[1+2\pi\sigma w(z_0-z)]^3$$

so that, so long as σw can be regarded as constant, $P(z-z_0)$ involves t only through the dependence of z_0 on t. We note that

(64) $$P(0)=1,\ P(\quad)=0$$

and that P is a steadily decreasing function.

Consider the equation

(65) $$z=z_\infty+w\quad t-g(t)\,Q\{h(t),\ z-z_0\}$$

where there is no loss of generality in taking

$$Q\{h(t),\ 0\}=1 \tag{66}$$

With this condition it is clear that successive partial derivatives of the function Q with respect to h will vanish at $(z-z_0)=0$. If, as we postulate, $z=z_\infty$ at $t=0$ it follows that

$$g(0)=0 \tag{67}$$

Denoting, as above, $(z-z_0)$ by $-d$, and differentiating with respect to t by $\cdot$, we have

$$\dot{z}=w_\infty-\dot{g}Q-g\dot{Q}=w_\infty-\dot{g}Q-g(\partial Q/\partial h)\dot{h}-g(\partial Q/\partial d)\dot{d} \tag{68}$$

If we also require $\dot{z}=w_\infty$ at $t=0$, it follows from (67) and (68) that

$$\dot{g}(0)=0 \tag{69}$$

At $z=z_0$ it follows from (68) that

$$\dot{z}_0\equiv w_0=w_\infty-\dot{g}(t) \text{ or } \dot{g}(t)=w_\infty-w_0 \text{ and} \tag{70}$$
$$g(t)=w_\infty t-z_0+(z_\infty)_0$$

by (65), so that in the case of the actual stream $\dot{g}$ and g are positive and increase with the time.

Differentiating (68) again with respect to t, we get

$$\ddot{z}=-\ddot{g}Q-2\dot{g}\left(\dot{h}\frac{\partial Q}{\partial h}+\dot{d}\frac{\partial Q}{\partial d}\right)-g\left\{\frac{\partial}{\partial t}\left(\dot{h}\frac{\partial Q}{\partial h}\right)+\ddot{d}\frac{\partial Q}{\partial d}+\dot{d}\frac{\partial^2 Q}{\partial t\partial d}\right\} \tag{71}$$

Putting $z=z_0$ this reduces to

$$\ddot{z}_0=-\ddot{g} \tag{72}$$

obtainable also from (70). Again, rewriting (71)

$$\ddot{z}\left(1-g\frac{\partial Q}{\partial d}\right)=-\ddot{g}\,Q-\left\{2\dot{g}\frac{\partial Q}{\partial d}+g\frac{\partial^2 Q}{\partial t\partial d}\right\}\dot{d}-2\dot{g}\dot{h}\frac{\partial Q}{\partial h}-g\left\{\ddot{z}_0\frac{\partial Q}{\partial d}+\frac{\partial}{\partial t}\left(\dot{h}\frac{\partial Q}{\partial h}\right)\right\} \tag{73}$$

In (65) z_∞ is one of the independent variables involved in z. Differentiating with respect to it, we deduce

$$\partial z/\partial z_\infty=1/(1-g\partial Q/\partial d) \tag{74}$$

thus, by (58)

$$\rho=\rho_\infty(1-g\partial Q/\partial d) \tag{75}$$

Substituting from (75) and (72) in (73), this becomes

$$\rho\ddot{z}=\rho_\infty\ddot{z}_0\left(Q-g\frac{\partial Q}{\partial d}\right)-\rho_\infty\dot{d}\left\{2\dot{g}\frac{\partial Q}{\partial d}+g\frac{\partial^2 Q}{\partial t\partial d}\right\}-\rho_\infty\left\{2\dot{g}\dot{h}\frac{\partial Q}{\partial h}+g\frac{\partial}{\partial t}\left(\dot{h}\frac{\partial Q}{\partial h}\right)\right\} \tag{76}$$

Putting $z=z_0$ we get

$$\rho_0\ddot{z}_0=\rho_\infty\ddot{z}_0\left[1-g\left(\frac{\partial Q}{\partial d}\right)_{z=z_0}\right] \tag{77}$$

which agrees with (75), and (77) may be rewritten as

$$(78)\qquad \rho\ddot{z}=\rho_0\ddot{z}_0\frac{Q-g\partial Q/\partial d}{1-g(\partial Q/\partial d)_{z=z_0}}-\rho_\infty\dot{d}\left\{2\dot{g}\frac{\partial Q}{\partial d}+g\frac{\partial^2 Q}{\partial t\partial d}\right\}$$
$$-\rho_\infty\left\{2\dot{g}\dot{h}\frac{\partial Q}{\partial h}+g\frac{\partial}{\partial t}\left(\dot{h}\frac{\partial Q}{\partial h}\right)\right\}$$

We now choose Q so as to satisfy the equation

$$\frac{Q-g\partial Q/\partial d}{1-g(\partial Q/\partial d)_{z=z_0}}=P(-d)$$

or

$$(79)\qquad \frac{\partial Q}{\partial(-d)}+Q/g=\left\{\left(\frac{\partial Q}{\partial(-d)}\right)_{z=z_0}+1/g\right\}P(-d)$$

With this choice of Q (78) becomes an approximation to (61) provided that the remaining terms on the right of (78) are small compared with $\rho_0\ddot{z}_0P$, and (65) is then an approximation to the solution of (61). For the present this will be assumed.

It then follows from (65) that Q must tend to zero as $(z-z_0)\to-\infty$ because for sufficiently large values of $-z$, at whatever time, $z=z_\infty+w_\infty t$, there being no retardation far within the stream. Hence the solution of (79) subject to this condition, is

$$(80)\quad Q(h,z-z_0)=\left[\{\partial Q/\partial(-d)\}_{z=z_0}+1/g\right]e^{-(z-z_0)/g}\int_{-\infty}^{z-z_0}P(\phi)e^{\phi/g}\,d\phi$$

The value of $[\partial Q/\partial(-d)]_{z=z_0}$ is determined by (66), which gives

$$(81)\qquad \{\partial Q/\partial(-d)\}_{z=z_0}+1/g=1/I$$

where

$$(82)\qquad I=\int_{-\infty}P(\phi)e^{\phi/g}\,d\phi$$

We shall define $h(t)$ by

$$(83)\qquad h(t)=1/g$$

Since $P(\phi)$ decreases steadily from unity when $\phi=0$, to 0 when $\phi=-\infty$, I is positive and less than g. Hence (79) and (80) may be re-written in the form

$$(84)\qquad \partial Q/\partial(-d)+Q/g=P/I$$

$$(85)\qquad Q(1/g,z-z_0)=(1/I)e^{-(z-z_0)/g}\int_{-\infty}^{z-z_0}P(\phi)e^{\phi/g}\,d\phi$$
$$=(1/I)\int_0^\infty e^{-\psi/g}P(z-z_0-\psi)d\psi$$
$$=\left\{\int_0^\infty e^{-\psi/g}P(z-z_0-\psi)\,d\psi\right\}/\left\{\int_0^\infty e^{-\psi/g}P(-\psi)\,d\psi\right\}$$

by slight changes in the variable of integration. Since $P(-d)<P(-d')$ if $d>d'>0$, the last form of Q shows that Q is less than 1 when

$-z$ exceeds $-z_0$ (that is, inside the stream), and that it decreases steadily from the head of the stream.

The excess mass accumulated in the head of the stream is, by (76), (81), (83)

$$(86)\quad m=\int_{-\infty}^{0}(\rho-\rho_\infty)\,d\,(z-z_0)=\int_{-\infty}^{0}\rho_\infty g\,\frac{\partial Q}{d(z-z_0)}\,d\,(z-z_0)$$

$$=\rho_\infty g\,[Q]^0_{-\infty}=\rho_\infty g=\rho_\infty\,[w_\infty t-z_0+(z_\infty)_0]$$

by (70). This simply means that the excess mass is that which would have been contained in the *compression interval*, as we may term the space $(wt-z_0+(z_\infty)_0)$ between the actual head of the stream (O) and the unretarded position (O') if the head of the retardation did not occur.

The proportionate excess density $(\rho-\rho_\infty)/\rho_\infty$ at any point is given by

$$(87)\qquad (\rho-\rho_\infty)/\rho_\infty=g\frac{\partial Q}{\partial(-d)}=-Q+gP/I$$

$$=\left[\int_0^\infty e^{-\psi/g}\left\{P(z-z_0)-P(z-z_0-\psi)\right\}d\psi\right]\Big/\int_0^\infty e^{-\psi/g}P(-\psi)d\psi$$

which is essentially positive, and decreases as $-(z-z_0)$ increases, that is, as we go onwards from the head of the stream.

When $P\,(\phi)=f^3=1/(1-2\pi\sigma w\phi)^3$, (88) may be expressed in terms of incomplete gamma functions. At the head of the stream Q and P are unity, and

$$(88)\qquad (\rho_0-\rho_\infty)/\rho_\infty=(-Q+gP/I)_{z=z_0}=g/I-1$$

$$=\left[\int_0^\infty e^{-\psi/g}\left\{1-P(-\psi)\right\}d\psi\right]\Big/\int_0^\infty e^{-\psi/g}P(-\psi)d\psi$$

The present calculations are based on the assumption that σw may be treated as constant. So far as w is concerned this may be taken as meaning that it must not differ from w_∞ by more than 10 per cent, and therefore that g, or $(w_\infty-w)$ is not more than $(1/10)\,w_\infty$; if $w_\infty=10^8$, this means that $g \ngtr 10^7$. The corresponding value of g will probably be at least 10^8, even allowing only about 20 seconds for this change in w to be produced. Thus g is a large number, far greater than the values of d that render f small (cf. §8.2). This implies that in I the factor $e^{-\psi/g}$ is nearly unity so long as P is appreciable, so that $I \doteq \int_0^\psi P\,(-\psi)\,d\psi=1/4\;\pi\sigma w_\infty$, and $(\rho_0-\rho_\infty)/\rho_\infty \doteq 4\pi\sigma w_\infty g$; this will be very large, if g is of order 10^8, for values of σ and w such as are considered in §8.2. The proportionate excess density at points within the stream is roughly $4\,\pi\sigma w_\infty g f^3$, so that the excess density $(\propto f^3)$ falls off from the head of the stream more rapidly than the magnetic field $(\propto f)$. Some such result was to be expected, because the excess density is due to relative retardation, which increases towards the head of the stream, on account of the increase both of H and of the current-density i.

Owing to the magnitude of g, again, the integration in the denominator of (89) can be approximately executed, giving

(89) $$Q\,(1/g,\, z-z_0) \doteq f^2$$

We also add the following approximate formulae:

(90) $$\frac{\partial Q}{\partial h} \doteq \frac{f(f-1)}{2\pi\sigma w_\infty},\quad \frac{\partial^2 Q}{\partial k \partial d} \doteq Q+2I\frac{\partial Q}{\partial d};\quad \frac{\partial^2 Q}{\partial h^2} \doteq -\frac{1}{(2\pi\sigma w_\infty)^2}(1-f)^2$$

8.41—It is desirable at this stage to show when the solution (65) is valid through the relative smallness of the remaining terms in (78) compared with the first two. We are concerned with the ratio

(91) $$R \equiv -(\rho_\infty/\rho_0 \ddot{z}_0 P)\left\{\dot{d}\left[2\dot{g}\frac{\partial Q}{\partial d} + g\frac{\partial^2 Q}{\partial t \partial d}\right] - 2\dot{g}\dot{h}\frac{\partial Q}{\partial h} - g\frac{\partial}{\partial t}\left(\dot{h}\frac{\partial Q}{\partial h}\right)\right\}$$

By using the relation (83) this becomes

(92) $$R = -(\rho_\infty/\rho_0 \ddot{z}_0 P)\left\{\dot{d}\left[2\dot{g}\frac{\partial Q}{\partial d} + g\dot{d}\frac{\partial^2 Q}{\partial d^2} - 2(\dot{g}/g)\frac{\partial^2 Q}{\partial h \partial d}\right] + (1/g)\left[-(\dot{g}/g)^2\frac{\partial^2 Q}{\partial h^2} + \ddot{g}\frac{\partial Q}{\partial h}\right]\right\}$$

By (68), (70)

(93) $$\dot{z}-\dot{z}_0 = -\dot{d} = \dot{g}\,(1-Q-(1/g)\partial Q/\partial h)/(1-g\partial Q/\partial d)$$
$$\doteq \dot{g}\,(1-Q)/(1-g\partial Q/\partial d),\ \text{by (90), and since}$$
$$g \text{ is large } (\dot{z}-\dot{z}_0) \equiv \lambda \dot{g}$$

where, as is proper, λ is 0 when $z=z_0$, and tends to 1 as $z \to -\infty$ (and hence as $f \to 0$); for values of $(z-z_0)$ which make $f=0{\cdot}01$, that is, corresponding to the point in the layer where shielding is 99 per cent complete, $4\pi\,\sigma\,w_\infty\,g\,f^3$ is 2×10^2 if $\sigma=(\sigma_e)_0$ and $w_\infty = g = 10^8$, so that there $\lambda = 5\times 10^{-3}$. Thus throughout the layer in which shielding is effected λ is very small.

By using the approximations given in (90) it is possible to reduce (91) to

(94) $$R \doteq (\lambda \dot{g}^2/g\ddot{g})\,\{(2-\lambda)\,(1-IQ/gP)+\lambda g\,\partial P/\partial(-d)/P\}$$
$$+2(IQ/gP)^2(f-1)\,\{1+2(f-1)\,(\dot{g}^2/g\ddot{g})IQ/gP\}$$

Now g, z_0, $\dot{z}_0$, w_∞ of §8.4 are approximately equivalent to the quantities which in §7.8 are denoted by z', z, v, and v_0. Hence, for values of z_0 such that w is not greatly different from w_∞, we have by §7.8

(95) $$g = aZ' = -a\,(1+\phi)/\gamma Z^5$$
$$= -a\,(\sqrt{\tfrac{1}{2}\gamma Z^6})/\gamma Z^5 = a^3/z_0^2\sqrt{(2\gamma)}$$

Also $\dot{g} = w_\infty - \dot{z}_0 = -w_\infty/\gamma Z^5 Z' \doteq w_\infty a^3/z_0^3\sqrt{(\tfrac{1}{2}\gamma)}$, and $-\ddot{g}$ or $\ddot{z}_0$ is the same as $\dot{v}$ (of §7·8), where $v = w_\infty\,(1-1/\phi)$; hence

$$\ddot{g} = w_\infty\,\dot{\phi}/\phi^2 = w_\infty\,\{(3\dot{Z}\sqrt{(2/\gamma)}\}/Z^4 = \{3a^3\dot{z}_0\,w_\infty\,(2/\gamma)\}/z_0^4$$

Thus so long as $\dot{z}_0$ is nearly equal to w_∞, as we have supposed throughout §8.4

(96) $$\dot{g}^2/g\ddot{g} \doteq 2/3$$

The term IQ/gP is approximately $1/4\pi\sigma wgf$ and therefore small throughout the effective shielding layer, being approximately 5×10^{-7} when $\lambda=5\times10^{-3}$; $\partial P/\partial(-d)=6\pi\sigma wf^4$ so that $g\partial P/\partial(-d)/P=6\pi\sigma wgf$ and $\lambda g\partial P/\partial(-d)/P$ is of order one throughout this part of the layer. The last term in (94) is therefore negligible and hence R is of the order $3\,\lambda\dot{g}^2/g\,\ddot{g}$ or approximately 2λ, which is small throughout the shielding layer.

8.42—The investigations of §§8.4, 8.41 have assumed that σ has the constant value $(\sigma_e)_0$: but one of the objects of this work was to determine the increase of density in the shielding layer, as the stream approaches the Earth, in order to see how far the excess density could compensate for the tendency of the magnetic field to reduce σ. We now proceed to apply the test of self-consistency to check this point, which depends on the value of αH (§8.1); so long as αH is small, $\sigma=(\sigma_e)_0$, which is nearly independent of N.

Now at a point z in the shielding layer, where $H=0.3\,fZ^{-3}$,

$$\alpha H=2\times10^{10}f/NZ^3 \tag{97}$$

by (48). Here N is the actual number-density at the point, and is to be distinguished from the N of §7.8, which may conveniently be denoted by N_∞. By §8.4, $N/N_\infty=\rho/\rho_\infty=4\pi\sigma w_\infty\,gf^3$, so that, if we take $\sigma=(\sigma_e)_0=1{\cdot}6\times10^{-9}$ e.m.u.

$$\alpha H \doteqdot 10^{18}/Z^3N_\infty w_\infty gf^2 \tag{98}$$

Further, by (95) and (41), $g=a/Z^2\sqrt{2\gamma}=a/Z^2\sqrt{(20\pi N_\infty Am_Hw_\infty^2/H_0^2)}$ so that

$$gw_\infty=2\times10^{19}/Z^2\sqrt{AN_\infty}$$

and

$$\alpha H \doteqdot \{\sqrt{A/N_\infty}\}/20Z\,f^2$$

Consider now the value of Z at which the reduction of speed of the head of the stream becomes 10 per cent. By (44) this implies that, in the notation of §7·8, $\phi=9$, and since for all but small values of Z we have $\phi=\sqrt{(5/2)}\zeta\equiv Z^3\sqrt{(1/2)}\gamma$, the corresponding value of Z is $9^{1/3}\,(2/\gamma)^{1/6}$ or $(81\,H_0^2/5\pi\,N_\infty\,Am_Hw_\infty^2)^{1/6}$ or $(2.8\times10^{23}/AN_\infty w_\infty^2)^{1/6}$. Thus $\alpha\,H$ at this point is $(A^2w_\infty/N_\infty)^{1/3}/1{\cdot}7\times10^5f^2$, which is greater, the greater the values of A and w_∞, and the smaller the value of N_∞, though the dependence on w_∞ and N_∞ is only proportional to the cube root. If $w_\infty=10^8$, $A=40$ (for Ca atoms), the corresponding values of Z and of αH are approximately 10 and $0{\cdot}03/f^2$ if $N_\infty=1$, or 3 and $0{\cdot}003/f^2$ if $N_\infty=1000$. Thus αH is small at the head of the stream, and for some distance inwards, certainly up to a point where $f=1/3$ in the former case, and $f=1/10$ in the latter. Hence the assumptions underlying the preceding work appear to be in no conflict with the results derived, for the most important part of the shielding layer. And though the analysis makes it appear that αH becomes one or more at greater depths in the shielding layer, implying that σ is there reduced below the value $(\sigma_e)_0$, we think that this is probably merely the result of unduly simplified assumptions adopted to render our investigation reasonably practicable. If at any stratum in the stream the density is insufficient to keep αH small, and consequently σ equal to $(\sigma_e)_0$, the reduced conductivity will decrease the current-intensity at that point; in this case the velocity of the electrons will be reduced below the velocity which they would have if σ_e

remained equal to $(\sigma_e)_0$, because they will tend to "hook" themselves on to the lines of force. But it seems likely that this effect will be compensated for by an increase of density which this retardation will produce; for the ions will still be free to move on, their spiral radius being still large compared with their mean free-path; thus they will tend to separate themselves from the electrons, but will be pulled back by the electric forces thereby set up,* tending to make them move on with the same reduced speed of the electrons. That is, matters tend to adjust themselves so that the ions and electrons keep together, and the density at each point takes the value necessary to maintain the full conductivity. In any case, if σ is somewhat less than $(\sigma_e)_0$ in the rear part of the shielding layer, this will tend to make σw more nearly constant, because w is reduced in the front part of the stream. Hence in our view our investigation supports the conclusion that the increase in density in the shielding layer neutralizes the tendency of the magnetic field to reduce the conductivity of the layer, and that at least until w is reduced by 10 per cent the conductivity due to the electrons is not appreciably impaired. Further, we think it likely, though without having examined the question quantitatively, that the same conclusion applies during the further retardation of the stream, so that the possible difficulties anticipated in the earlier parts of this section will not arise. But further modification of the investigation of this section needs to be considered before all the important aspects even of our simplified problem have been taken into account; this modification is concerned with the effects of the pressure gradient that would accompany the heaping-up of matter at the head of the stream. The extended analysis will be given in §9; it is unfortunately still more complicated than the analysis of this section. Owing to the difficulty even of the restricted problem here treated, it seemed desirable to discuss this before taking up the more complete analysis.

(*To be continued*)

*This electric force in the direction of motion will, jointly with the magnetic field, tend to make the electrons move in the $-y$ direction, constituting a current in the $+y$ direction, and thereby making the electrons contribute to the conduction current of the ions despite the small electronic spiral radius.

EIN VORSCHLAG ZUR ERGÄNZUNG DER MAGNETISCHEN JAHRBÜCHER

Von G. Fanselau

Für sehr viele magnetische Untersuchungen, die auf die Originalangaben der magnetischen Jahrbücher zurückgreifen, ist es ein oft sehr störend empfundener Übelstand, dass die von einer festen Abzugszahl aus gerechneten, veröffentlichten Werte durch die Säkularvariation besonders für weit auseinander gelegene Zeitpunkte ihre Vergleichbarkeit verlieren. Auf diesen Übelstand ist vor allem von Ad. Schmidt[1] aufmerksam gemacht worden, auf dessen Veranlassung hin im Potsdamer Jahrbuch wohl auch zuerst diesem Umstand Rechnung getragen wurde.

Den Verfahren zur Elimination der Säkularvariation liegt gewöhnlich die Annahme eines zeitlich linearen Ganges dieser Erscheinung innerhalb eines Jahres zu Grunde. Diese Annahme ist in voller Schärfe sicher nicht erfüllt, und infolgedessen muss ein solches Eliminationsverfahren notwendig einige Unsicherheiten in sich tragen. Die explizite Berücksichtigung des säkularen Ganges während eines Tages ist daher im allgemeinen wohl kaum erforderlich, ganz abgesehen davon, dass die dann vielleicht zu bildenden Stundenkorrektionen in der weitaus grössten Mehrzahl der Fälle so klein sind, dass sie weit unter der bisher zu erreichenden Genauigkeit liegen. Hinzu tritt noch die eben erwähnte tatsächlich vorhandene Unsicherheit in der Erfassung der Säkularvariation, deren wahre Grösse kaum sicher genug abgeschätzt werden kann. Im allgemeinen erscheint es daher angebracht bei den Säkularkorrektionen nicht über die Tageskorrektionen hinaus zu gehen. Um hier nun ohne viel Aufwand an Arbeit dem Benutzer die Möglichkeit zu geben, sich über die Grösse des säkularen Ganges zu orientieren, schlage ich vor, dass die Observatorien in ihren Jahrbüchern laufend eine Tabelle bringen, die die Säkularkorrektionen der zur Veröffentlichung gelangenden drei Elemente enthält gültig für die Mitte des Monats. Ferner in einer weiterer Tabelle die Tageskorrektionen für die Tagesmitte bezogen auf die bereits angegebenen Monatskorrektionen. Als Genauigkeit dieser Korrektionen dürfte wegen der bereits genannten Unsicherheit der Säkularvariation im allgemeinen $0'.1$ bei den Richtungsangaben und ein γ bei den Kraftangaben ausreichen. Solche Tabellen sind aus Anlass einer grösseren Untersuchung über die Nachstörung am Potsdamer Observatorium für eine ganze Reihe von Jahrgängen verschiedener Observatorien berechnet worden. Sie werden demnächst gesondert für sich zur Veröffentlichung gelangen, um die hier einmal geleistete Arbeit auch für andere Untersuchungen nutzbar zu machen.

Ein Beispiel möge zeigen, in welcher Weise die Rechnung und Veröffentlichung geschehen kann. Es seien A und E die Normalwerte (Mittelwerte vom 1. Juli bis 30. Juni) eines Elements zu Anfang und Ende eines Jahres. Dann ist zu bilden: $m=\triangle/\mu$ und $t=\triangle/\tau$, mit $(E-A)=\triangle$, $\mu=$ der Anzahl der Monate, τ der Tage. Es muss dann m auf 10^{-2}, t auf 10^{-3} genau berechnet werden, soll in den Korrektionen die bereits erwähnte Genauigkeit von 1γ bzhw. $0'.1$ erzielt werden. Als Bezugspunkt der Korrektionen innerhalb eines Jahres dient zweckmässigerweise der Normalwert am Jahresanfang. Die erste Tabelle enthält nun die für die Monatsmitte gültigen Zahlen $-m/2$, $-3m/2$, ..., $-23m\ 2$, sachgemäss abgerundet auf die eben erwähnten Einheiten. Die zweite

[1]Ad. Schmidt, Abweichungen des fortlaufend gebildeten Tagesmittel vom Normalwert. See Terr. Mag., 25, 65-71 (1920).

Tabelle bringt die Tageskorrektionen $-t+(m+t)/2$, $-2t+(m+t)/2$, ..., $-32t+(3m+t)/2$, ..., wobei natürlich bei der Abrundung dieselbe Korrektion für mehrere Tage hintereinander gültig sein kann. Das Glied $t/2$ in der Tageskorrektion, das ja wegen der Gültigkeit dieser Korrektion für die Tagesmitte strenggenommen berücksichtigt werden muss, darf wegen seiner Kleinheit in der weitaus grössten Zahl

Tabelle 1—*Baldwin 1908: Säkular-Korrektionen gültig für die Monatsmitte*

Element	Jan.	Febr.	März	April	Mai	Juni	Juli	Aug.	Sep.	Okt.	Nov.	Dez.
D	−0′.1	−0′.2	−0′.3	−0′.5	−0′.6	−0′.7	−0′.9	−1′.0	−1′.1	−1′.3	−1′.4	−1′.5
H	2γ	7γ	12γ	16γ	21γ	26γ	30γ	35γ	40γ	44γ	49γ	53γ
Z	1γ	3γ	5γ	6γ	8γ	10γ	12γ	14γ	16γ	17γ	19γ	21γ

Tabelle 2—*Baldwin 1908: Tägliche Säkular-Korrektionen*

Korr.	Jan.	Febr.	März	April	Mai	Juni	Juli	Aug.	Sep.	Okt.	Nov.	Dez.
						Deklination						
′												
+0.1	1–12	1–4	..	1–13	1– 6	..	1–14	1– 7	..	1–15	1– 7	..
0.0	13–31	5–27	1–21	14–30	7–29	1–21	15–31	8–30	1–22	16–31	8–30	1–23
−0.1	..	28–29	22–31	..	30–31	22–30	..	31	23–30	..	..	24–31
						Horizontal-Intensität						
γ												
−3	..	..	1– 2	..	..	1– 2	..	..	1– 2	..	..	..
−2	1– 3	1– 5	3– 9	1– 4	1– 7	3– 9	1–5	1– 7	3– 9	1– 5	1– 7	1– 3
−1	4–10	6–12	10–15	5–11	8–13	10–15	6–11	8–13	10–15	6–11	8–13	4– 9
0	11–16	13–18	16–22	12–17	14–20	16–22	12–18	14–20	16–22	12–18	14–20	10–16
+1	17–23	19–25	23–29	18–24	21–27	23–28	19–25	21–26	23–28	19–24	21–26	17–22
+2	24–30	26–29	30–31	25–30	28–31	29–30	26–31	27–31	29–30	25–31	27–30	23–29
+3	31	..	..	..	..	..	..	..	..	..	..	30–31
						Vertikal-Intensität						
γ												
−1	1– 8	1–10	1–15	..	1– 3	1– 5	1– 8	1–11	1–13	..	1	1– 4
0	9–25	11–27	16–31	1–17	4–20	6–22	9–25	12–27	14–29	1–16	2–18	5–21
+1	26–31	28–29	..	18–30	21–31	23–30	26–31	28–31	30	17–31	19–30	22–31

der Fälle vernachlässigt werden. Sein Einfluss kann höchstens bei der Abrundung merkbar werden und so vereinzelte nahe an der Abrundungsgrenze stehende Werte um eine Einheit erhöhen oder erniedriegen. Die Tabellen 1 und 2 zeigen an einem Beispiel (Baldwin 1908), dass die hier vorgeschlagene Methode gegenüber der laufenden Angabe der Korrektionen für jeden Tag mitunter erheblich an Platz und damit auch an Kosten spart. Die geringen Unregelmässigkeiten in dem an sich als gleichmässig angenommenen Gang sind lediglich Abrundungserscheinungen. Der hiermit begangene Fehler beträgt ja höchstens 0.5γ bzhw. 0′.05, kann also bei den meisten Untersuchungen über Säkularvariation mit in Kauf genommen werden. Aus der Tabelle findet man so z. B. für Baldwin: 1908, April, 13—D, $-0'.5+0'.1=-0'.4$ und H, $+16+0=16\gamma$; August, 31—D, $-1'.0-0'.1=-1'.1$ und H, $+35+2=37\gamma$.

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AURORAL OBSERVATIONS AT THE ALASKA AGRICULTURAL COLLEGE AND SCHOOL OF MINES, 1930-31—Concluded[1]

By Veryl R. Fuller

Aurora journal, November 17, 1930, to April 17, 1931—The following pages summarize the journal of the photographic work done. Many of the photographs taken were either spoiled due to the plate-holders leaking light, too short an exposure, or to the unusability of the negatives due to indistinct outline.

November 17, 1930: The aurora was first seen at 18:00 rather dimly as a narrow arc. Observers went to Station 2 but no pictures were taken because the aurora was too weak. It died out completely at 23:00. The sky became overcast about 24:00 and continued so during the remainder of the night.

November 24, 1930: At 17:30 a faint arc was seen near the horizon. The observers were at their posts at 19:30 and work began. Five pictures were taken but these were not usable because the lens had slipped out of focus and therefore this set of the pictures was spoiled. The aurora had died down by 21:30 so the observers returned home. Later it came out again.

November 26, 1930: Aurora was first seen at 20:00. The observers were sent to Station 2, but no pictures were gotten until late; then four exposures were made. They were of no value.

December 2-3, 1930: At 22:30 a faint glow was seen in the north. This changed into a weak arc low in the north at 23:00. The observers were ready and three exposures were made which failed. The aurora was gone at 1:30 December 3. These exposures could have been used with a great amount of intensification and by outlining the aurora with ink.

December 20-21, 1930: Everything was ready by 21:00 but the aurora had died down. The first photograph was taken at 24:25 and five others were taken by 1:20. The aurora was especially good, brilliantly colored and changing shapes. When the plates were developed, however, they were all fogged. The plates had been in the holders for over a week and I find that these plate-holders must be reloaded each time they are used and then wrapped in black paper or the plates become fogged.

December 28-29, 1930: The aurora was first seen at 23:10 as a weak arc low in the north. The observers were ready to work by 24:15 but the aurora had become very diffuse and died out completely by 24:30.

January 9-10, 1931: A faint glow was first seen in the north at 16:30. This lasted only a short time. At 19:00 a faint arc was seen extending from about 20° west of north to east. This became rapidly brighter and then faded at 19:10. At 22:00 an arc was seen at an altitude of about 75°. This became steadily brighter until 22:40, when it changed to a rapidly moving form showing color and ray-structure. At 22:45 this whirling, twisting band broke up into segments and began to fade and spread over the entire north half of the sky. At 1:00 the display reappeared as a homogeneous band, very brilliant, moving rapidly and showing color. Eleven pictures were taken between 1:15 and 2:15. Of these only four could be used.

January 13-14, 1931: At 22:20 a faint arc was seen in the north. The observers were started at once for Station 2, but before they could reach there the aurora had become very faint and as a result only one photograph was taken and this was worthless. By 24:45 the sky had become completely overcast so that nothing more could be done.

January 17, 1931: A faint curve was seen as a glow in the northeast near the horizon at 19:20. The observers were dispatched to be ready should a good display occur. The glow resolved itself into a faint homogeneous arc at 21:30 very near the horizon. Two pictures were taken but they were unsuccessful. The sky had become completely overcast by 22:30 and observation stopped.

January 21, 1931: At 20:00 a quiet arc was seen extending from northwest to east. It was near the horizon. The observers were sent to Station 2 and three photographs taken. They were unusable.

January 23-24, 1931: The aurora was first seen at 22:15 as a faint arc near the northern horizon. By 23:00 the display had faded out and at 24:40 the observers came home. No pictures were taken.

January 26-27, 1931: The aurora came out at 22:30 as a homogeneous arc extending from northwest to east. It was rather weak during the first part of the evening, coming and going. At 1:00 four pictures were taken; these were too weak to be used. At 2:00

[1]Continued from this Journal, 36, 297-308 (1931).

I had the observers return home. They had no sooner started when the display reappeared. At 2:20 a most beautiful homogeneous band extended clear across the sky showing ray-structure and varying colors. Its motion was very rapid. At 2:30 it had faded out. At 2:43 it reappeared as a faint arc in the north. At 2:45 it had again become very brilliant. At 2:50 this band broke up into patches and at 3:00 had completely disappeared.

January 27-28, 1931: At 21:00 a faint arc was observed extending from north to east and having a height at its center of about 65°. At 21:25 this arc changed into a homogeneous band which soon died out leaving only a luminous glow across the sky. The observers were at their post at 22:30 and work began. At 22:50 an arc was seen near the northern horizon. Two photographs were obtained of this. At 23:00 the aurora had died out. At 23:05 it had come out again, and again two photographs were taken and again the aurora died out. It did not appear until 24:15, when suddenly an homogeneous band appeared moving very rapidly. It died out almost as rapidly, but again two pictures were gotten. It did not reappear until 1:10, when it came out as a series of arcs becoming diffuse as the number of arcs increased. Twelve exposures were made in all, eight of which were usable.

February 8-9, 1931: The aurora was first observed at 21:45 as an arc extending from northwest to northeast with the center of the lower border at an elevation of ten degrees above the horizon. By 22:40 it had increased in brightness and had become double. At 23:15 the display had died out. At 24:15 it had reappeared and work began. Five exposures were made, none of which were good.

February 9-10, 1931: At 19:45 a display was seen having the form of a weak homogeneous band. The observers started for Station 2 but had car trouble and did not reach there until shortly after midnight. During this time the sky had begun to cloud over and only two exposures were possible. These could not be used.

February 14-15, 1931: At 17:00 a faint arc was seen near the northern horizon. It remained quiet and soon died out not to come out again until about 21:30, when it lasted again only a few minutes. At 1:00 it reappeared and ten pictures were taken, seven of which were usable.

February 15-16, 1931: An arc was observed at 21:20 extending from northwest to east. By 22:20 it had become quite intense but remained near the horizon. By 22:50 it had reached an altitude of about 30°. At 23.18 it changed to a ray-structure forming a partial corona, then died out completely. At 24:25 it reappeared and became quite intense, moving rapidly across the sky, lasting until 24:45, when it died out. The aurora came out again at 1:00 and showed an arc-form until 1:20 when it changed to ray-structure, forming a partial corona again at 1:45. By 2:15 it had entirely disappeared again. Ten pictures were taken during the evening, only three of which could be used.

March 13-14, 1931: At 20:00 the aurora formed a quiet arc across the sky from north to east rather strong and remaining without motion for about an hour, when it died down to come back later. Due to bad roads the observers were unable to reach Station 2 until after midnight. Twelve exposures were made between 1:00 and 2:00. None of these could be used due to fogged plates.

March 15-16, 1931: The aurora was first seen as a faint arc extending from northwest to east at 19:30. It remained so until 20:40, when it became more intense and began to move at its eastern end into a partial spiral. At 22:30 it had almost disappeared. At 23:10 a very weak arc was visible. At 24:40 it began to reappear and became quite intense. Six photographs were taken, only one of which was usable.

April 9, 1931: Aurora was first observed as a quiet arc, quite strong and stretching across the sky from northwest to east at 22:00. At 23:00 it had died down. At 23:30 a faint arc was visible at the northern horizon. Observers were on duty but no exposures were made.

April 10-11, 1931: At 21:20 a faint arc was seen in the northeast. At 22:00 rays had appeared in the northeast reaching to the zenith. At 22:40 it had died out. At 1:50 a faint arc was visible in the northwest to east. Observers were on duty from 23:00 on. The aurora was so weak, however, that no exposures were made.

April 12-13, 1931: The display was first seen at 24:20 as a very faint arc in the northeast. Shortly after it disappeared, to return at 24:45, then changing rapidly into a homogeneous band which took on a ray-structure. At 1:10 it assumed a very pronounced ray-structure and faded rapidly, being entirely gone at 1:28. Observers did not reach Station 2 until after the display had gone.

April 17-18, 1931: Beginning at 20:30 a faint arc was seen at an altitude of about 35° extending from northwest to east. The display lasted until 1:50. At 24:00 midnight when work began it was a rather diffuse band showing some ray-structure. Thirteen exposures were made, of which seven could be used.

Calculations—In calculating the height and position of the aurora the procedure is the same as that used by others. It is outlined briefly here.

The photographs are projected onto a screen, thus being enlarged to such an extent that one degree is equal to one centimeter on the screen. The outline of the aurora is then drawn on paper and the positions of several stars are indicated. This is done for each of the pair of parallactic photographs.

Several stars are next selected, two or three, sometimes four, and their positions calculated for the time when the photograph was made. This calculation consists in changing the coordinates given in the Nautical Almanac, which are for the oblique sphere, to coordinates on the right sphere. To do this the following equations are used from spherical trigonometry.

$$\begin{aligned}
\sin h &= \sin \phi \sin \delta + \cos \phi \cos \delta \cos t \\
\sin a &= \cos \delta \sin t \sec h \\
\cos a &= - \cos \phi \sin \delta \sec h + \sin \phi \cos \delta \cos t \sec h \\
\sin k &= \sin a \cos \phi \sec \delta \\
\sin k &= \sin t \cos \phi \sec h \text{ (this formula is used as a check)}
\end{aligned}$$

where h = height of star above horizon; a = azimuth of star; k = angle between the vertical circle passing through the star and circle of declination; δ = declination of the star; t = hour-angle of the star (calculated from Nautical Almanac); and ϕ = latitude of the station.

The next step is to calculate the angular distance along a great circle from the point on the celestial sphere, where the line from Station 1 to Station 2 intercepts it, to the star. Then the angle between this great circle and the vertical circle passing through the star is calculated.

To make this calculation the following three equations were used

$$\begin{aligned}
\cos u &= \cos h \cos (a - a_0) \\
\cot \lambda &= \sin h \cot (a - a_0)
\end{aligned}$$

and as a check

$$\sin u \sin \lambda = \sin (a - a_0)$$

In these, u = angular distance along great circle from projection of the base-line to celestial sphere and star; $(a - a_0)$ = difference in azimuth of the base-line and that of the star; λ = angle between u and h.

When these above calculations are made for each of the two or three stars for each pair of pictures, the tracings are placed on the appropriate "network" chart and points on the aurora are chosen, after which by use of the "network" and the calculated values of h, u, λ, k, and a, the direction of the parallax, and its amount can be measured.

The value of the parallax, p, measured in this way is then substituted in the equation

$$r = g \sin (u + p) \csc p$$

in which r = distance from Station 1 to the point on the aurora; g = length of the base-line.

The height above the Earth and the distance along the surface of the Earth can now be measured graphically by setting a straight-edge, pivoted at the point representing Station 1 on a graph representing a cross-section of the Earth's surface, at the angle, h, of the point on the

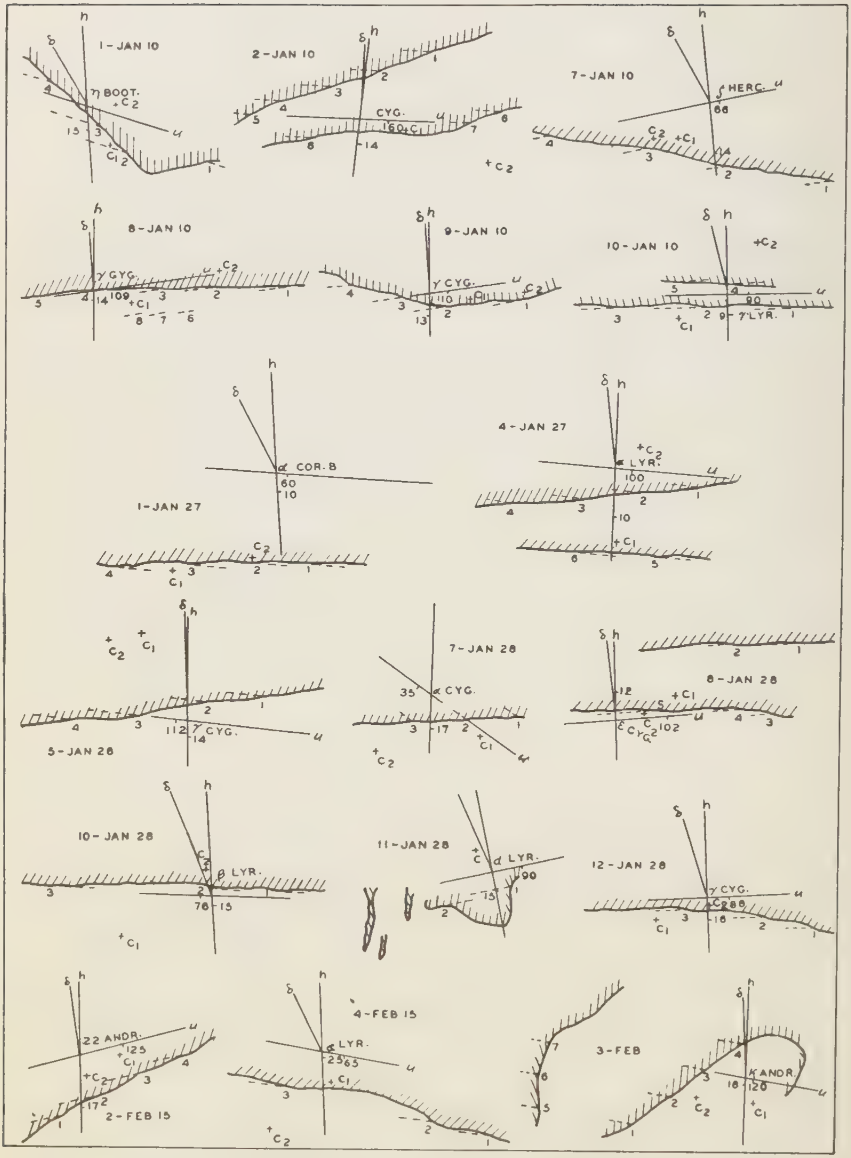

FIG. 1—Sketches showing different points measured for aurorae of January 10 to February 15, 1931, photographed at stations 1 and 2, College, Alaska

TABLE 2—*Particulars and computed heights, distances, and azimuths of auroral points from Station No. 1 calculated from parallactic photographs made at College, Alaska, January to April 1931*

Date	G.M.T.			Exp. No.	Exp. time	Pt. No.	Height, distance, and azimuth of point			Remarks
							H	*D*	*a*	
1931	*h*	*m*	*s*		*s*		*km*	*km*	°	
Jan. 10	0	29	30	1	19	1	100	376	283.9	An arc of moderate intensity in NE and E
						2	98	296	282.1	
						3	98	265	276.7	
Jan. 10	0	58	50	2	25	1	320	635	198.3	A double arc
						2	416	816	192.2	
						3	190	480	188.8	
						4	184	497	185.0	
						5	177	530	180.1	
						6	365	990	199.5	
						7	350	990	197.2	
						8	207	660	183.6	
Jan. 10	1	22	10	7	10	1	124	572	239.8	Diffuse luminous surface and arc
						2	143	580	230.5	
						3	146	520	224.6	
Jan. 10	1	26	50	8	19	1	203	612	201.0	Very weak arc
						2	188	574	195.8	
						3	134	425	189.9	
						4	132	428	184.6	
						5	119	400	179.4	
						6	168	582	194.2	
						7	212	710	192.2	
						8	195	659	188.6	
Jan. 10	1	29	55	9	17	1	174	575	203.9	A single arc
						2	108	385	185.7	
						3	121	410	181.5	
						4	125	400	178.3	
Jan. 10	1	32	41	10	9	1	86	440	210.2	A double arc
						2	90	346	202.5	
						3	87	396	193.6	
						4	91	398	203.6	
						5	90	228	199.7	
Jan. 27	10	57	00	1	17	1	95	740	237.0	Upper one of two arcs
						2	114	731	233.6	
						3	111	806	227.3	
						4	125	870	220.7	
Jan. 27	11	21	20	4	17	1	234	770	201.9	Double arc
						2	102	394	197.3	
						3	210	772	191.5	
						4	115	614	186.0	
						5	85	512	198.8	
						6	87	535	191.7	
Jan. 28	0	16	50	5	9	1	108	319	191.4	Single arc
						2	119	356	186.4	
						3	100	321	180.2	
						4	99	330	175.4	
Jan. 28	0	20	45	7	18	1	235	615	276.0	Single arc
						2	194	524	271.5	
						3	351	830	167.0	
Jan. 28	1	03	05	8	16	1	142	442	206.6	Double arc
						2	160	490	200.3	
						3	148	680	203.5	
						4	145	660	199.9	
						5	136	620	193.5	
Jan. 28	1	42	40	10	10	1	156	461	226.9	Single arc
						2	94	287	221.6	
						3	91	268	207.1	
Jan. 28	2	03	40	11	10	1	82	290	204.8	Single band
						2	235	778	199.6	
						3	350	832	193.5	
Jan. 28	2	06	46	12	10	1	110	352	216.1	Single arc
						2	120	370	211.6	
						3	131	382	204.9	

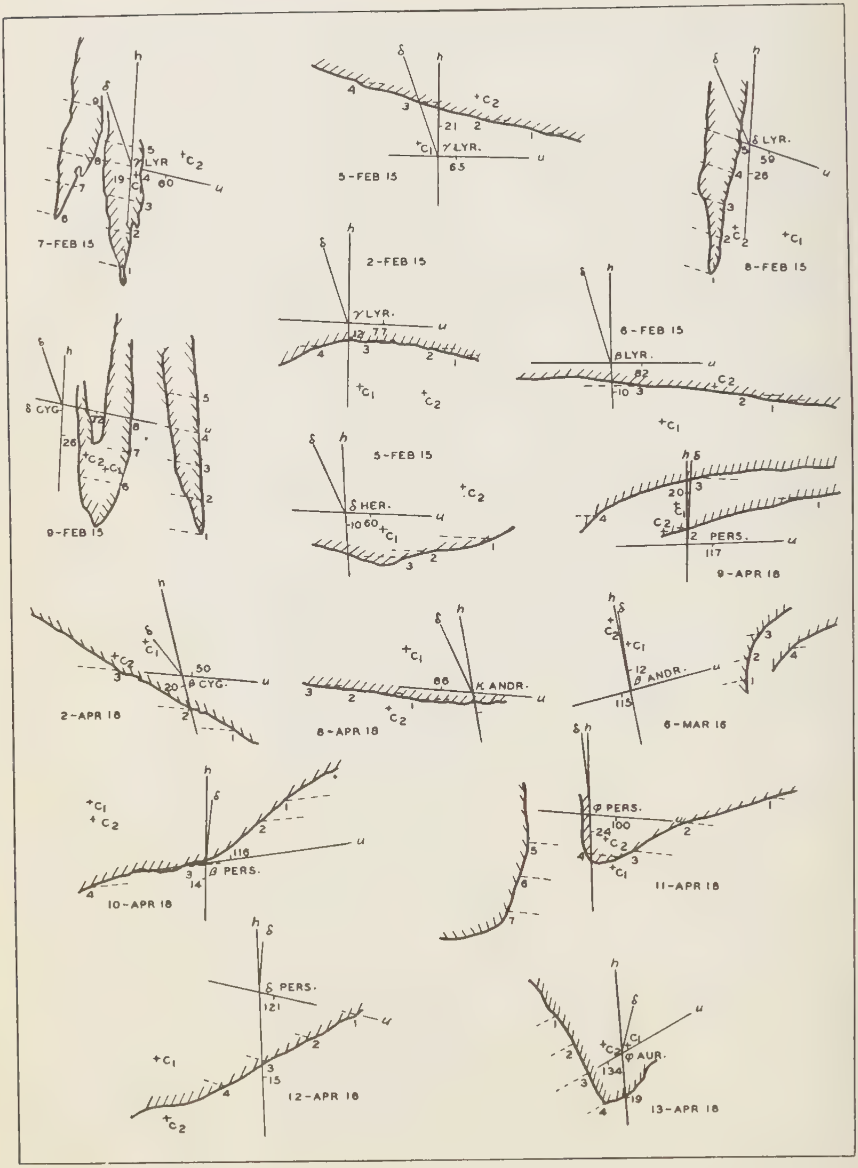

Fig. 2—Sketches showing different points measured for aurorae of February 15 to April 18, 1931, photographed at stations 1 and 2, College, Alaska

TABLE 2—*Continued*

Date	G.M.T.			Exp. No.	Exp. time	Pt. No.	Height, distance, and azimuth of point			Remarks
							H	*D*	*a*	
1931	*h*	*m*	*s*		*s*		*km*	*km*	°	
Feb. 15	1	16	14	2	20	1	207	599	163.0	A band
						2	162	438	166.5	
						3	141	351	169.9	
						4	124	290	173.2	
Feb. 15	1	18	55	3	20	1	144	476	162.8	A band
						2	127	371	165.9	
						3	136	351	168.8	
						4	166	372	172.4	
						5	139	450	154.2	
						6	152	415	154.2	
						7	164	388	156.3	
Feb. 15	1	21	45	4	10	1	90	248	246.7	Single arc
						2	96	251	241.5	
						3	89	251	229.8	
Feb. 15	1	23	20	5	16	1	118	286	235.0	Single arc
						2	175	384	237.9	
						3	120	309	242.1	
Feb. 15	1	44	05	7	14	1	108	462	235.4	Rays
						2	134	437	235.4	
						3	111	328	236.3	
						4	130	326	236.0	
						5	128	293	235.9	
						6	140	480	229.5	
						7	134	390	230.5	
						8	95	242	232.1	
						9	102	208	232.6	
Feb. 15	1	55	15	8	11	1	124	366	236.7	Rays
						2	152	378	237.0	
						3	154	334	237.2	
						4	172	337	237.7	
						5	201	338	238.3	
Feb. 15	1	58	00	9	16	1	111	310	235.3	Rays
						2	163	385	235.1	
						3	178	362	234.5	
						4	232	425	234.1	
						5	122	280	228.4	
						6	130	258	228.7	
						7	139	247	229.4	
Feb. 15	11	12	23	2	16	1	226	856	226.4	An arc
						2	185	718	223.9	
						3	209	760	218.6	
						4	253	955	214.4	
Feb. 15	11	36	03	5	15	1	93	561	237.8	An arc
						2	81	482	240.1	
						3	83	475	242.2	
Feb. 15	11	37	42	6	20	1	111	325	225.1	An arc
						2	109	512	223.3	
						3	104	461	213.7	
Mar. 16	1	39	55	6	14	1	160	735	191.7	A band
						2	199	767	192.2	
						3	184	643	193.9	
						4	283	1028	195.9	
Apr. 18	0	26	50	2	20	1	97	315	252.6	Diffuse arc
						2	118	328	248.7	
						3	133	302	243.7	
Apr. 18	0	59	25	8	20	1	154	326	209.7	Diffuse luminous surface
						2	108	226	205.1	
						3	212	427	102.4	
Apr. 18	1	01	00	9	20	1	165	420	187.6	Brilliant bands
						2	243	667	176.5	
						3	108	260	176.7	
						4	138	378	168.7	

TABLE 2—*Concluded*

Date	G.M.T.			Exp. No.	Exp. time	Pt. No.	Height, distance, and azimuth of point			Remarks
							H	*D*	*a*	
1931	*h*	*m*	*s*		*s*		*km*	*km*	°	
Apr. 18	1	02	00	10	20	1	110	259	186.8	Bands with ray-structure
						2	106	188	180.6	
						3	162	506	176.2	
						4	151	534	169.3	
Apr. 18	1	03	30	11	20	1	·376	650	216.0	Arc with ray-structure
						2	222	442	199.6	
						3	146	328	195.0	
						4	116	263	190.2	
						5	175	370	186.5	
						6	156	379	185.8	
						7	152	429	184.6	
Apr. 18	1	05	05	12	20	1	470	990	178.2	Arc with ray-structure
						2	263	660	175.0	
						3	275	760	171.1	
						4	146	481	167.6	
Apr. 18	1	31	30	13	15	1	376	651	153.1	An arc
						2	210	436	154.2	
						3	180	412	155.2	
						4	214	491	156.4	

aurora being measured, measuring, *r*, along this straight-edge to a suitable scale and dropping a perpendicular to the Earth's surface at this point. The length of this perpendicular and the distance of its base to Station 1 are the height, *H*, and the distance, *D*, respectively for that point on the aurora. The azimuth, *a*, of the point is obtained from the "network."

Table 2 gives the values of *H*, *D*, and *a*, for the different points on the aurora for the photographs measured, as well as the times for each exposure. All angles are measured in degrees and minutes; all distances in kilometers.

Reference may be made to Figures 1 and 2 for sketches showing the different points of the auroral photographs given in Table 2.

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AN APPARATUS FOR REGISTRATION OF THE AURORA BOREALIS

By Leiv Harang

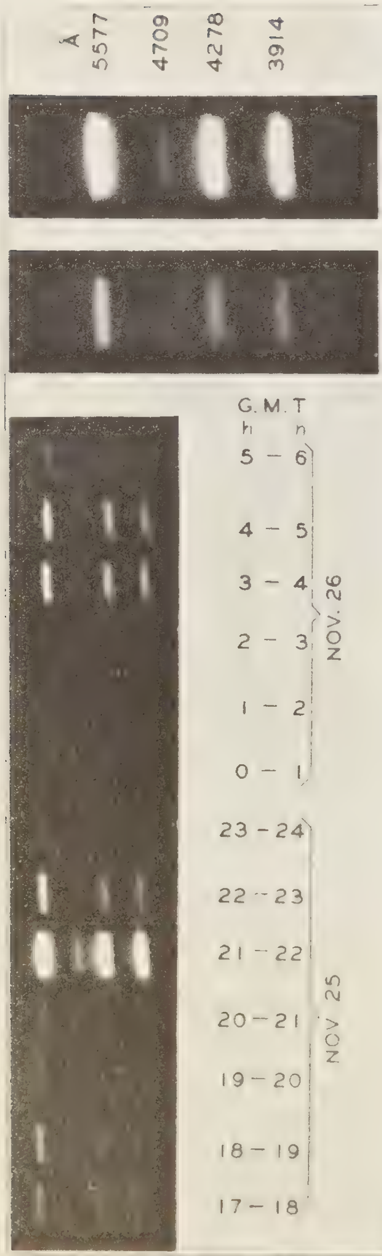
In statistical treatments of the aurorae, visual observations usually have been used. During the winter 1930-31 an objective registration of the aurora borealis at the Observatory of Aurora Borealis in Tromsö has been tried, using an apparatus described below.

The registering-apparatus consists of a small spectrograph of very high light power, and a movable plate-holder which is displaced 3.2 mm automatically every hour.

The collimator and camera-lenses, which are identical, are made from one piece of glass. The diameter of the lenses is 50 mm and the focal length 50 mm—the aperture-ratio thus is 1:1. The lenses are spherically ground, but with the radii chosen the spherical aberration is reduced to a minimum[1]. The chromatic aberration of the camera-lens is of no significance as the picture of the slit is focussed on the plate as a number of spectral lines with different wave-lengths. The chromatic aberration of the collimator-lens makes the light passing through the lens not strictly parallel in all wave-lengths, which causes a loss in definition of the spectral lines; as the spectrograph is not intended for wave-length measurements, this is of less importance. The plate-holder is clamped to the base-plate in a fixed position and the spectral lines are focussed on the plate by moving the camera lens. The prism is a 60° prism of flint glass. A broad slit, 1.0−0.5 mm, is used during exposure. The plate-holder is moved by a gramophone-motor, which is operated through a magnetic relay by the central clock-work in the Observatory. In front of the slit a mechanical shutter is placed, which is operated by a small motor. The shutter is also connected with the central clock-work in the Observatory and closes the register at any desired time. The register is placed with the slit pointing against the north at an elevation of about 60°. Because of the great aperture of the collimator-lens, aurorae over the greater part of the northern sky are registered. Figure 1 is a reproduction of a spectrum of the aurora taken with this apparatus and Figure 2 shows the record obtained during one night. The spectra reproduced in Figures 1 and 2 were taken on very green-sensitive "Agfa-Isochrom" plates; but plates with high speed in violet and ultra-violet, such as "Imperial 1200 H & D" and "Barnet, Press Plates 1500 H & D", have also been used with success. The results of the registrations will be published later.

Appendix—The records reproduced in Figure 2 were obtained November 25, 1930. On the evenings of November 24, 25, and 26 there was in Tromsö a period with aurorae of quite unusual character and intensity. After a period of some days with faint and quiet aurorae, there occurred on the evening of November 26 aurorae of quite unusual character. Usually a display of aurorae is inaugurated by the occurrence of quiet arcs or bands which gradually develop into more vivid forms—pulsating bands, draperies, and rays. On the evening of November 24 the display was inaugurated by a display of very vivid rays—some were violet, others had a deep green colour—corresponding to light of wave-

[1]The lenses were made by Messrs. Dr. Steeg and Reuter, Bad Homburg v. d. H., Germany.



length 5300-5000 A. As the rays often appeared and disappeared in the course of less than one second, it was difficult to get photos of these interesting rays and only a small number of parallactic photos were obtained. The next evening, November 25, a display of very intensive quiet auroral forms—arcs, bands, and pulsating bands—occurred. The colour on that date was the usual green-yellow. The following evening, November 26, the display of more quiet auroral forms was repeated though less intensive. On November 25, 1930 at the Greenwich Observatory a solar eruption of great intensity was observed with the spectrohelioscope. From *Nature* (p. 696, 1930) the following description is reprinted: "The phenomena observed on November 25 evidently represented the end-on view of an eruptive prominence blown out of the Sun's chromosphere with a maximum observed velocity of 450 km/sec. Forty-five minutes before the eruption, an apparently stable dark marking was visible; at $10^h 34^m$ G.M.T. the velocity rose within a few minutes from 40 km/sec to about 400 km/sec. At 11^h cloud stopped the observations, but the eruption was then declining, and part of the gaseous structure was descending at about 100 km/sec. Contemporary with the appearance of those rapidly moving masses of hydrogen gas, brilliant patches of hydrogen with little or no radial velocity made their appearence."

The occurrence of the aurorae on November 24-26, 1930 is an example of the strong connection between great sunspot-activity and brilliant aurorae.

Nordlysobservatoriet,
Tromsö, Norway

AURORAL OBSERVATIONS AND MAGNETIC CONDITIONS AT THE SITKA MAGNETIC OBSERVATORY, JULY 1931 TO JUNE 1932[1]

By Franklin P. Ulrich

This paper is a continuation of the reports,[2] begun in 1923, of the investigation concerning the relation between aurora and the Earth's magnetic field. The investigation of the Earth's magnetic field and its relation to radio reception was discontinued with the report for 1928-29 because of the lack of proper sensitive instruments and because this investigation is being taken up elsewhere in a more detailed manner than was possible at this Observatory.

Instruments and methods—The instruments and methods as outlined in the report for 1923–24 were used during these observations.

Auroral frequency—The following log shows the frequency of aurora on clear and partly cloudy nights at the Sitka Magnetic Observatory. Observations were made usually up to 23^h and reports after that time were only casual. The number in parentheses indicates the character of the Earth's magnetic field at the time of the observations on the international scale of 0, 1, and 2. All time is standard 135th west meridian time.

1931, Sept. 13—Clear; steady glow along north sky-line; (0). Sept. 14, 15—Clear; feeble glow along north sky-line; (0). Sept. 16—Partly cloudy; aurora reported for short period around 20^h; (1). Sept. 17—Partly cloudy; no aurora; (1). Sept. 20—Partly cloudy; no aurora; (0). Sept. 24—Clear; no aurora; (0).

1931, Oct. 3—Clear; no aurora; (0). Oct. 19—Clear 22^h to 23^h; no aurora; (1). Oct. 21—Clear; no aurora; no magnetograph-record from October 20 to November 1 because of installing new magnetograph. Oct. 25, 26, 27—Clear; no aurora.

1931, Nov. 3—Clear; faint rays and curtain observed for short period around 21^h; (2). No aurora at 22^h; (2). Aurora reported later during the night; (2). Nov. 7—Partly cloudy; no aurora; (1). Nov. 12—Clear; no aurora; (0). Nov. 13—Clear; feeble glow along north sky-line; (1). Nov. 14, 15—Clear; no aurora; (0). Nov. 16, 17—Clear; no aurora; (1). Nov. 18—Clear; no aurora; (0). Nov. 19—Partly cloudy; no aurora; (0). Nov. 24, 25—Clear; no aurora; (0). Nov. 26—Clear; no aurora; (1).

1931, Dec. 5, 6, 7, 8—Clear; no aurora; (0). Dec. 9—Clear; feeble glow along north sky-line; (1). Dec. 10—Partly cloudy; no aurora; (0). Dec. 11, 12, 15, 18, 19, 20—Clear; no aurora; (0). Dec. 25—Partly cloudy; no aurora; (0).

1932, Jan. 11—Clear; steady glow along north sky-line between azimuth 205° and 255°; (1). Jan. 15—Clear; no aurora; (0). Jan. 25—Partly cloudy; no aurora; (1). Jan. 26—Clear; steady glow along north sky-line at 23:30; (1). Jan. 27, 29—Clear; no aurora; (0). Jan. 30—Clear; no aurora; (1).

1932, Feb. 2, 3—Clear; no aurora; (1). Feb. 4—Clear; a few small groups of rays were visible just before 22^h; (2). Each group lasted only a short time. At 22^h all of the rays had disappeared and a feeble glow hung along the north sky-line and up to about elevation 30°; (1). Fog ascending from the mountains shut out the aurora shortly after this. Feb. 28—Clear with fog along north sky-line; no aurora; (0). Feb. 29—Clear; no aurora; (0).

1932, Mar. 1, 15, 26—Clear; no aurora; (0). Mar. 28—Clear; no aurora at 20^h; (0). Pale glow at 22^h; (1). Cloudy at 24^h.

[1]Published by permission R. S. Patton, Director, United States Coast and Geodetic Survey.

[2]For previous reports see Terr. Mag., **30**, 150-151 (1925), **33**, 162-165 (1928), **34**, 301-302 (1929), and **36**, 309-310 and 239-241 (1931).

1932, Apr. 5—Partly cloudy; feeble glow along north sky-line; (1). Apr. 6—Partly cloudy and cloudy along the north sky-line; glow above the clouds at times; (2). Rays reported for a short period around 23^h; (1). Apr. 12, 18, 19—Clear; no aurora; (0). Apr. 22—Clear; pale glow along north sky-line; (1). Few rays noticed for short period around 22:30; (2). Apr. 23—Clear; feeble glow along north sky-line; (1). Few rays along sky-line at 24^h; (1). Apr. 24—Clear; at 22:45 rays and homogeneous arc covered north sky up to elevation 45°; color, pale yellow; (2). At 23^h the rays had disappeared except a few faint rays but the arc remained for some time and then gradually descended until it became a feeble glow along the north sky-line; (2). Apr. 25—Clear; feeble glow and rays along north sky-line; (1). Apr. 26—Clear; bright aurora reported between 1^h and 2^h; (2). Feeble glow and faint rays along sky-line; (1). Apr. 27—Clear; glow and faint rays along north sky-line; (1). Bright group of rays reported for short period around 21:30; (2). Apr. 28—Clear to 22^h; no aurora; (1). Apr. 29, 30—Clear; no aurora; (0).

1932, May 1—Clear; no aurora; (1). May 2—Clear; rays and arc up to 30° elevation at 22:45; (1). No aurora at 22:55; (1).

Summary—During this past season there were 71 clear or partly cloudy days so that aurora could have been noted if it occurred. On several of these days observations were made on more than one occasion so that in all 82 observations were made. On these 82 observations aurora was noted 28 times. This is the greatest frequency of aurora that has been recorded since the auroral log has been kept. The following table is a summary of the past five years.

Year	Observations	Aurora
1927–1928	78	15
1928–1929	84	11
1929–1930	71	19
1930–1931	59	5
1931–1932	82	28

On four of these days of observations there was no magnetic record because of installing the new magnetograph and hence, a comparison between the aurora and the Earth's magnetism will be made on the basis of 78 observations. There were no auroras on 36, 13 and 1 days when, magnetic characters were (0), (1), and (2), respectively, while there were auroras on 3, 16, and 9 days when magnetic characters were (0), (1), and (2), respectively.

The three auroras that occurred on (0) days were feeble glows. Of the 16 auroras occurring on (1) days nine were glows along the north sky-line and 7 were brighter auroras or auroras reported to the observer by other people. Of the nine auroras occurring on (2) days, eight were of the brighter type and the other one was recorded as a glow at a higher elevation with clouds hanging along the north sky-line at the lower elevation.

This is the second time that the observer has recorded no aurora on a (2) day. The record shows that this observation was for one particular time, there being bright aurora just before this time and bright aurora was reported to the observer later during this same night.

Sitka Magnetic Observatory,
Sitka, Alaska

PROBLEMS IN ATMOSPHERIC ELECTRICITY AT APIA, WESTERN SAMOA

By K. C. Sanderson

Determination of influence of height of tide on reduction-factor of Lagoon-Station, August 3, 1931

All previous determinations of the reduction-factor for the lagoon-station at the Apia Observatory have been made either at Watson's Island, about one-quarter mile east of the lagoon-house, or in the lagoon southward from the main observatory buildings. The actual places used were in the first case a flat rocky shelf and in the other a flat stretch of sand both of which are laid bare at low-tide. Since the flat stretches are covered with water before half-tide, observations have thus been confined to low-water or thereabouts. It was thought that the rise and fall of the sea-level with the tide had no influence on the reduction-factor on account of the concrete platform about eight feet square beneath the collector, which formed a permanent earth-plane.

On July the 16th a stretched-wire determination was made at Watson's Island. On this day the tide was exceptionally low being more than one foot below the usual level of low-water. The mean reduction-factor for the lagoon-station was found to be correspondingly low while that for the land-station was still the same as in previous observations. This strengthened the belief that the reduction-factor actually did change

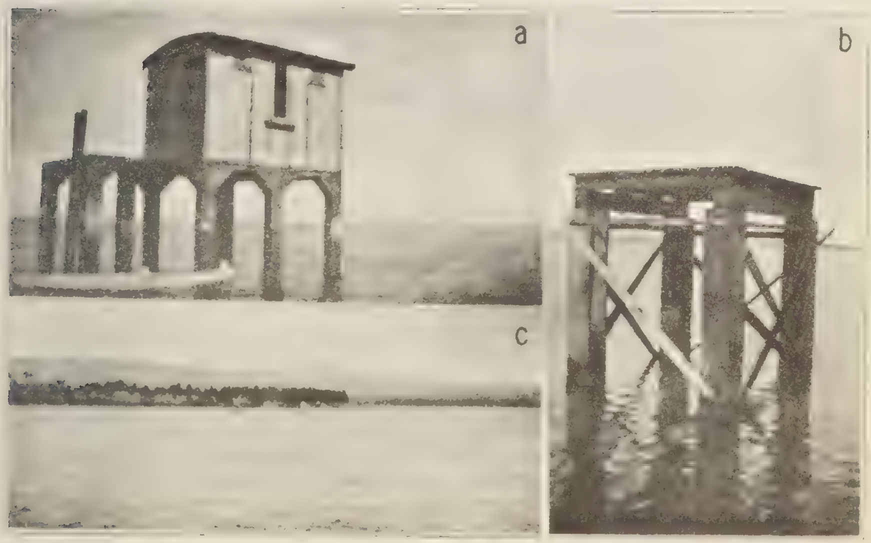


Fig. 1—(a) Lagoon-station, showing concrete platform beneath collector-rod which projects from the center of the wall; (b) platform erected on concrete piers for use with raft in future stretched-wire observations to determine reduction-factors for the two stations (photograph taken at low-water); (c) showing platform in lagoon with Observatory in background, the platform being almost exactly midway between the two stations

with the height of the tide. In order to ascertain exactly how it did change it was necessary either to find a place where stretched-wire observations could be made at both high- and low-water, or to build a platform or raft which would rise and fall with the tide. No place sufficiently free from obstacles could be found anywhere near the Observatory. A raft was therefore constructed in the form of a light frame-work which floated level with the surface of the water. The two posts, between which the wire was stretched were the only parts of the raft above the water. The distance between the posts was 13 metres. The wire was insulated from the posts by specially made heavy sulphur-insulators. The first experiments with the raft were a failure because the whipping of the wire caused by motion of the raft in a short choppy sea broke the sulphur-insulators and also caused the collectors to oscillate widely. These difficulties were overcome by staying the posts more rigidly, and by using stronger and heavier sulphur-insulators. The wire was stretched very tightly thus preventing nearly all the movement of the collectors. The height of the collectors above the level of the sea measured in smooth water was slightly less than one metre, being 98 cm.

The raft was moored lengthwise in the direction of the prevailing wind at a distance of about 65 metres from the lagoon-station. The stretched wire was connected to the Wulf electrometer located just inside the door of the hut by means of a long thin wire which led first to a sulphur-insulator to take the strain and then to the electrometer.

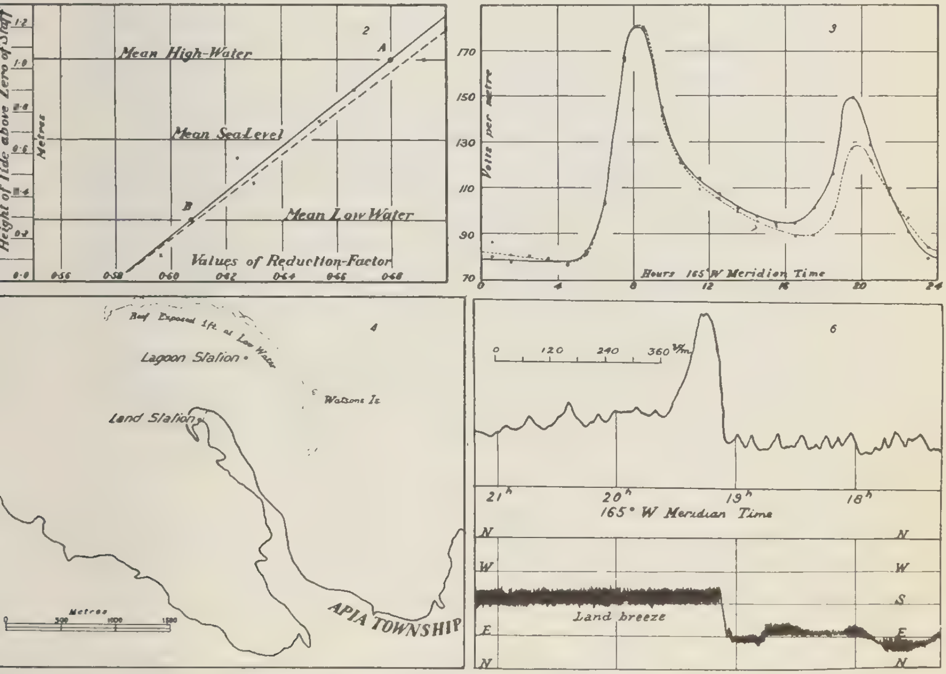
Observations were continued for 4½ hours. During this time the level of the water fell 0.57 metre. As the tide receded the value of the reduction-factor approached more and more nearly that deduced from the observations at Watson's Island (on days of normal low-tides), which is at present used in the reduction of the lagoon-station records. The mean reduction-factor for the land-station was in good agreement with those obtained from previous observations. Thus it would seem that the raft was not influenced much if any by its proximity to the lagoon-station.

This line of investigation has been pursued by comparing the land-station records with the lagoon-station records grouping days from the latter when high- and low-water occurred at the same time, and comparing these with simultaneous days from the land-station. Days were chosen when either high- or low-water occurred at the hours of the maxima, that is about 8^h or 20^h.

The ratio land-station/lagoon-station was then evaluated for 225 simultaneous hourly values at the two stations when high-water occurred at the above hours and for 182 hourly values when low-water occurred at the same times. The mean of the former gave a value 1.079 and for the latter 0.980; so that it would seem that, assuming the reduction-factor of the land-station to be 1.00, the reduction-factor for the lagoon-station at high-water should have been 0.680, and that for low water 0.607.

The foregoing results are shown diagramatically in Figure 2, the dotted line being plotted from observations on the raft and the points *A* and *B* from the ratios land-station/lagoon-station for high-water and low-water, respectively. There is a very marked agreement between these two lines which have thus been derived quite independently. The height of mean sea-level deduced from several months readings is 0.67

metre above the zero of the tide-gauge staff. The value of the reduction-factor taken at this point is 0.646 as against the mean reduction-factor of 0.630 which is at present applied to all values recorded at the lagoon-station.



FIGS. 2, 3, 4, and 6—(2) Changes in nature of reduction-factor at lagoon station with height of the tide; the full lines show the ratio of the land-station value to the lagoon-station value for selected hours, while the dashed line shows this ratio as determined from experiments on raft, August 3 and observations July 16; (3) Diurnal variation of the atmospheric potential-gradient at land (full line) and lagoon (dotted line) stations, Apia, 1929-1930; (4) sketch-map showing location of land, lagoon, and absolute stations, and surroundings; (6) comparison between electrograms at the land-station and record of wind-directionon November 5, 1931, at the Apia Observatory

Comparison of the diurnal variation of the potential gradient at the land- and the lagoon-stations

Figure 3 shows the diurnal variation of the potential gradient at both land- and lagoon-stations. The curves are drawn from the means of the hourly values for 218 days at the land-station and 216 days at the lagoon-station, only undisturbed days free from negative electricity being used. It should be noted that the days were not necessarily the same for both stations, and that in reducing the lagoon-station records to volts per metre the reduction 0.646 was used—the approximate reduction-factor at mean sea-level.

The curves show quite good agreement from the period 1^h to 2^h up to 15^h to 16^h. However in the second maximum occurring in the early

evening there is a marked discrepancy between the mean values at the two stations.

It has been shown that the diurnal variation of the electric potential-gradient over the Pacific Ocean in tropical regions is due primarily to a single 24-hour wave progressing approximately according to universal rather than local time. The maximum of this wave occurs at about 8^h 165° west meridian time and corresponds exactly with the greater maximum shown at both land- and lagoon-stations. The second maximum which is characteristic of most land-stations is generally not present at ocean-stations. The question now arises as to how far from the shore the apparent influence of the land extends. Unfortunately there appears to be no data at present available on this subject. But it would seem possible from the fact that the second maximum at the lagoon-station is so much smaller than that at the land-station that the former may be tending to become actually a sea-station. The fact that the diurnal-variation curve of the potential gradient at the land-station at Apia is too widely different from the characteristic curve for the Pacific Ocean has been commented on before (Researches Dept. Terr. Mag., v. 5 p. 276).

A rough idea of the position of the lagoon-station with regard to the nearby land is given in Figure 4. The land shown is all very low—in particular the narrow peninsula on which the observatory is situated which is nowhere more than four feet above mean sea-level.

Dissimilarities at the two stations

Although situated only about 650 metres apart on various occasions, very different conditions persisting for fairly long periods have been observed at the two stations. A good example of this is shown in Figure 5 which shows the records for 17^h to 18^h September 18, 1931 when

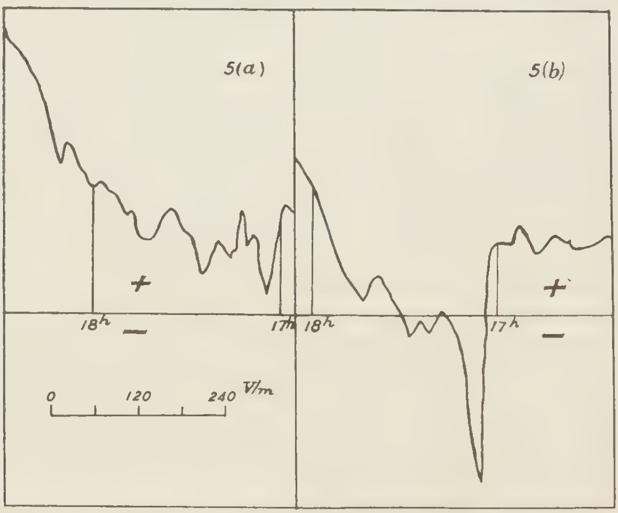


Fig. 5—Electrograms at lagoon (a) and land (b) stations for the same period during September 18, 1931

negative electricity was recorded at the land-station for over 30 minutes while at the lagoon-station the air-potential was positive. Usually this can be explained as due to the effect of heavily-charged cumulus and cumulus-nimbus clouds which accumulate over the hills and whose influence does not always extend as far as the lagoon-station. The classification of the days at the two stations is thus not always the same, for example, September 18 would be classed as a disturbed day at the land-station and an undisturbed day at the lagoon-station.

The evening maximum and the land-breeze

Observations extending over several years seem to reveal a marked connection between the evening maximum and the land-breeze. Figure 6 shows a typical example of this. Although this may possibly explain the absence of the secondary maximum over the open ocean, it does not account entirely for the difference in the diurnal-variation curves of the potential gradient at the land- and lagoon-stations during the early evening (Fig. 3). The writer has frequently observed that the land-breeze is quite apparent at distances greater than six kilometres from the shore. It seems hardly likely therefore, that the distance between the two stations is sufficient to cause the above difference.

Apia Observatory,
Apia, Western Samoa

REVIEWS AND ABSTRACTS

(See also page 182)

NOLAN, J. J., AND J. G. O'KEEFFE: *Electric discharge from water drops.* Dublin, Proc. R. Irish Acad., A, v. 40, 1932 (86-98).

The general method followed by Zeleny, who examined the electric discharge from liquid points in the form of hemispherical drops, was followed in this investigation. In contrast to Zeleny, however, who adjusted the hydrostatic pressure within the drop so as to compensate for the distorting effect of the electric field, the distortion due to the field was allowed to occur, thus more closely imitating a free drop exposed to an atmospheric field.

Contrary to the results of Zeleny, where a positive discharge was found to occur at the same potential difference as a negative discharge, the present results showed a negative discharge occurring at a lower potential than a positive discharge, and a negative discharge-current being always greater than a positive discharge-current.

The value of the field at which a rapid discharge sets in at a suspended drop, in agreement with the results found previously by Wilson and Taylor, was found to be connected with the radius of the drop by the approximate relation, $F\sqrt{r}+3600$, where F is the intensity of the uniform undisturbed field in volts per cm and r is the radius of the drop in cm. It was consequently concluded that in atmosphere containing only small drops, no reaction between the field and the drops will occur until the field has reached such a value that sparking occurs. If the drops are above a certain size, however, the field will act on the drops before sparking is possible. The negative discharge being more intense than the positive, the drops acquire a positive charge, which eventually cause the drops to burst, even if the field does not grow to that somewhat higher value at which it would directly distort and burst the drop.

The ions produced in the discharge are all small ions, the large ions come about only through the small ions attaching themselves to Aitken nuclei already present in the atmosphere. The charge per large ion was found to be of the order of magnitude of 3000 electronic units. In the type of discharge investigated, there was no disintegration of the liquid surfaces of such a kind as to produce Aitken nuclei which would become large ions upon receiving a charge from the small ions which are present in large numbers.

This investigation was carried out under conditions more representative of those in the free atmosphere than in the case of previous workers, and in this respect therefore, it has additional value. The results have application in the studies of thunderstorm-electricity and also in other phases of atmospheric-electric phenomena where raindrops are present in an intense electric field.

G. R. WAIT

GUTENBERG, B.: *Handbuch der Geophysik*, herausgegeben von B. Gutenberg. Band 6, Lieferung 1. Berlin, Gebrüder Borntraeger, 1931 (v+312 mit 134 Abb.). 27 cm.

The development of geophysical methods as applied to underground prospecting has been so rapid in recent years that it has been found necessary, in the case of the 10-volume Handbuch der Geophysik now in course of publication under the editorship of B. Gutenberg, to devote the entire sixth volume to this subject. The proposed plan of this volume calls for ten contributions by various specialists, but the first part now before us contains only four of these which deal with the electrical and gravimetrical methods of applied geophysics.

The first contribution, by H. Reich, is devoted to a discussion of the properties of rocks (density, elasticity, electrical conductivity, magnetic susceptibility, etc.) which play a decisive part in this branch of geophysics, thus serving as an introduction to the detailed consideration of the different methods to follow. H. Hunkel opens the next article on electrical methods with a brief historical sketch of their development, thence proceeding to a detailed exposition of the methods of this group which have proved of greatest value in the past and seem to promise most for the future. He treats the methods in three main groups, (1) those utilizing natural earth-currents, (2) those based on electrical currents artificially introduced into the ground, and (3) high-frequency methods. The last method, however, has not yielded as satisfactory results as were at first expected from it. The article is concluded with a discussion of the practical importance and future development of electrical methods.

The last two articles contain detailed discussion of the gravimetrical method, E. A. Ansel treating the theoretical aspects and O. Meisser describing the instruments used in this method.

H. D. HARRADON

A NOTE UPON VERTICAL INTENSITY AT THE APIA OBSERVATORY

By C. J. Westland

At the Apia Observatory the north pole of the magnet rises, so that vertical intensity is negative. The practice adopted to facilitate tabulation is to disregard signs, and in this way the reading which has the *largest numerical value is called the maximum.* The hourly values of vertical intensity, Z, are computed in the same manner as those of horizontal intensity, H, and of declination, D, namely from the mean ordinate to the curve during the entire period of 60 minutes commencing at the hour of Greenwich mean time stated. In the harmonic analysis the notation is

$$Z = m + r_1 \sin (A_1+t) + r_2 \sin (A_2+2t) + \ldots\ldots$$

The diurnal variation of vertical intensity at Apia is subject to an annual variation which has the effect of producing a second maximum and minimum during a portion of the year. The usual curve is a simple one, having its maximum value about 16^h, after which it descends steadily to its minimum about 2^h. But during November, December, and January, the curve after making some progress in its descent from maximum at 16^h, shows a recovery and forms a second maximum about 23^h or 0^h, after which it falls rapidly and reaches minimum in the usual way about 2^h. As a general rule these second maxima and minima are found in October and February also. This period of five months is clearly centered upon the December solstice, but the fact that its duration from October to February corresponds with the season during which the Sun is south of the zenith at Apia is evidently fortuitous. In 1930 the second maxima and minima are found on the magnetograms in March and April. It is the first time this has happened during the time I was in charge of the magnetic work at Apia, but other instances of it are found in the reports prepared by my predecessors. On at least one occasion the second maximum and minimum were recorded in September.

Table 1 shows the results of harmonic analysis of the diurnal variation of Z in each month from August 1929 to July 1930, with exception of March, during which the variometer-record was not satisfactory. It is interesting to note the behavior of the phase-angle of the second term, A_2. In August and September sin A_2 and cos A_2 are both negative, so that the angle is in the third quadrant, between 180° and 270°. In October the cosine-term becomes positive, so that the angle is in the fourth quadrant, between 270° and 0°. In November both the sine and cosine are positive, so that A_2 has moved into the first quadrant, and in December it is found in the second. Then it turns back, and during January, February, and April it is in the first quadrant again. In May it has returned to the fourth quadrant, and in June and July it is back again in the third quadrant where it was in August 1929, at the beginning of the period.

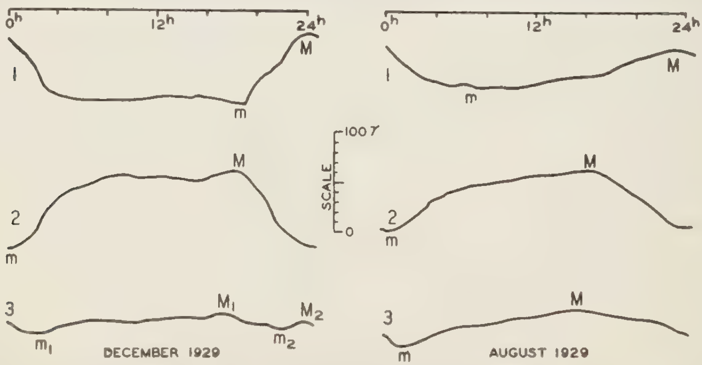
Some explanation of the formation of the second maximum may be found if we take the diurnal variation of horizontal intensity as our starting point. The general form of this curve does not change much during the year, but its range is large at the time of the December solstice, and produces a rather high maximum about 23^h. In the graphs below the first curve plotted is that of the logarithms of H, the second is that of log tan I, and the third is the sum of the first and second, that is of log Z. M_2 and m_2, in December, are produced by the maximum in

TABLE 1—*Results of harmonic analysis of diurnal variation in vertical intensity, August 1929 to July 1930*

Month	Amplitude				Phase-angle			
	r_1	r_2	r_3	r_4	A_1	A_2	A_3	A_4
1929	γ	γ	γ	γ	°	°	°	°
Aug.....	5.21	1.58	0.30	0.10	209	227	243	77
Sept.....	3.80	1.39	0.45	0.38	216	239	200	214
Oct.....	6.14	0.54	0.37	0.10	239	347	112	28
Nov.....	2.32	0.75	0.71	0.36	213	76	94	121
Dec.....	2.13	1.44	0.95	0.45	198	108	148	147
1930								
Jan.....	2.29	1.12	1.04	0.55	209	79	111	156
Feb.....	3.60	0.39	0.50	0.17	222	57	127	172
Apr.....	3.51	0.63	0.36	0.40	233	63	111	127
May....	2.80	0.05	0.23	0.11	225	285	247	278
June....	2.09	0.64	0.33	0.15	239	243	198	167
July....	4.83	1.07	0.34	0.22	219	233	236	253

the top curve. For August 1929, it is clear that the much flatter maximum in log H is insufficient to produce a second maximum in log Z.

It is much more interesting, however, to attempt to construct a theory that the annual variations in H and Z are both effects of the Sun's



influence, and fortunately we really find a clue to start with. As already stated the ranges included between highest and lowest hourly values in H have their greatest value in December and their least value in June. But if we take the twelve ranges from the individual months in any of the years 1925 to 1929 and plot the twelve points, then the curve drawn through them can not be distinguished from a sine-curve. In fact the curves may be expressed by equations of the form, $R\gamma = a - b \sin \delta$, in which δ is the mean value of the Sun's declination during the month referred to. The values of a for these years, 1925 to 1929, are respectively, 42, 47, 45, 45, and 47, which look rather like a constant affected by small errors. In 1923 and 1924 the twelve points do not give recognizable curves, but in 1920, 1921, and 1922 the sine-curve appears again, only here the value of a has diminished to 38.

Wellington, New Zealand

THUNDER-STORM PROBLEMS IN ATMOSPHERIC ELECTRICITY[1]

By C. E. Deppermann, S.J.

Cumulus caps—Because of conflicting claims with reference to their connection with thunder-storms, special attention was given to the so-called cumulus "caps." "Cap" is used to mean one of those limited sheets of cloud which often appears right above a cumulus top, but which soon after is either pierced by the cumulus as it rises or gently falls upon the cumulus, or clings to it. While in the first stage, that is, while a small sheet, usually curved, directly above the cumulus, it is most properly called a cap.

During the spring and summer of 1931, there was a most unusual opportunity of studying these caps at Manila because of the protracted thunder-storm period. The types observed were very varied, but may be grouped under five types. (*a*) The first type is a sharply outlined layer, usually but not always curved, often reminding one forcibly of a white-penciled eyebrow; the layer may be very sharp, or wide like a ribbon, single or multiple, faint or densely white; cumuli have been seen with as many as four or five superimposed caps. (*b*) The second or misty type results when, during an active thunder-storm, the first type settles on top of the cumulus and thickens, as is often the case, to form a mist, generally brilliantly white; there may be included in this type also the bright white mist into which the existing thick stratus is changed by a rising cumulus. (*c*) The flocculus type, in which a continuous sheet is not formed, consists of little clouds like some forms of alto-cumulus. (*d*) The pennant type is really only a cap of the first or second type, wind-blown to one side. (*e*) The wispy or smoky type is formed at times if a cumulus top very slowly falls after just getting a cap; the top seems to be connected with the place of the former cap by smoke-like wisps or tendrils. There can be absolutely no question that caps can occur at other than cirrus heights, as this phenomenon has been observed at Manila times almost without number, especially when the air is much stratified.

It has been stated very positively and as positively denied that there can be no lightning unless the cumulo-nimbus has been "capped" at *cirrus* height. The writer has had no experience in investigating the thunder-storms outside of Manila, but with regard to thunder-storms at that place it can be stated that in all unambiguous cases no lightning has ever been observed until the cumulus has been capped at *cirrus* height. At Manila, no cumulus gave lightning if capped only at heights lower than cirrus. This statement must be taken carefully as it stands. Unambiguous cases are comparatively rare, since the following conditions must be fulfilled: (*a*) The cumulus must be watched practically from its infancy to be sure of observing the very first lightning or of hearing the

[1]By courtesy of Director M. Selga, S.J., of the Manila Observatory, the Journal has the privilege of publishing this abstract of Dr. Deppermann's forthcoming article in the Publications of the Manila Observatory under the title "Studies in atmospheric electricity—No. 2". For a summary of the first communication "Air-potential registration at the Manila Observatory, October 1927 to December 1930" see Terr. Mag., **36**, 231-237 (1931).

very first thunder; (*b*) the cloud-arrangement must be such as to give an unobstructed view of the top of the cumulus. Ten of the more decisive cases observed are described briefly in the complete article.

Development of initial large potential—In the relatively few cases where it was possible to make simultaneous observations of cap-formation and of the development of initial large potential associated with the formation of caps, the process seemed to be as follows: A rapid drop to decidedly negative values of potential gradient was coincident with or followed soon after the formation of a cirrus cap; thunder was heard or lightning was seen soon after the drop commenced, that is, in from two or three to fifteen minutes later.

With regard to the relation between the formation of intense electric fields and the consequent lightning and thunder, irrespective of caps many observations were possible. Relying upon evidence of very many cases, we may say that the general rule is that the first lightning is preceded, not by a slow, but by a rapid development of electric field. No record was obtained of a storm that started and developed directly overhead, but in storms developing near enough to influence the Benndorf electrometer the initial potential-change in a developing thunder-storm is usually a rapid drop (requiring ten to fifteen minutes) to low negative values of gradient, the storm apparently remaining at the same approximate distance from the place of observation.

Are large dark cumuli always electrically charged?—This may be answered in the negative. Many cases have been observed at Manila of really gigantic cumuli, directly overhead, with no apparent effect on the potential. In fact, the bases of the cumuli may be quite dark and threatening and the clouds may start to drop and resolve into mist, or even rain gently to the ground with scarcely the slightest effect being noticed. However, a shower of some violence, even without thunder and lightning, generally causes negative values of the gradient.

Some types of clouds influencing the electric field—Around the base of a thunder-storm there is usually a fringe of lower cumuli of modest height and of rather dark stratus, apparently often formed by the rain falling from above and arrested in its flight to the ground. When such clouds are carried by the wind away from the main storm towards the place of observation, the result is almost invariably a high positive gradient. If the false cirrus, flung out from a thunder-storm in a banner of stratus, becomes mammato-like in structure and rains or snows down to lower levels, the usual result is a decided rise of potential gradient, even though no rain should fall to the ground.

Initial wind-gusts from a thunder-storm—In the course of a thunder-storm at Manila, one more interesting phenomenon must be mentioned. At the first decided breeze from the direction of the oncoming thunder-storm, the gradient has been observed almost invariably to go decidedly positive for a little while, even though a minute before it may have been almost off the electrometer-scale with negative values.

Usual potential-changes during a thunder-storm—Provided that no preliminary lower clouds come overhead, that no complications arise from the raining down of the false cirrus, and that there is no large preliminary rush of air from the storm-direction, the general run of potential gradient in a heat thunder-storm at Manila is somewhat as follows:

(*a*) A decided initial fall to negative values, the amount depending on the nearness of the storm; the drop may be quite sudden if the cumulus becomes a cumulo-nimbus not many miles away, but is slower if it is caused by the gradual approach of a fully developed storm. (*b*) If there is rain before the darker scud clouds, etc., arrive, this rain is rather gentle and is usually accompanied by comparatively slow lessening of the negative potential. (*c*) With the coming of the scud and darker clouds of the more intimate part of the storm, there is usually a rise to positive values, which at times may be numerically as great as the previous negative values. (*d*) The record then becomes usually very complicated, with positive and negative oscillations caused by the combined effect of cloud-potential, charged rain, and lightning. (*e*) In the latter part of the storm we usually find more gentle rain with moderately negative gradient. (*f*) Finally, as the rain gradually slows up, the potential gets increasingly negative for a while until the cumulo-nimbus has entirely passed, after which there is a rather slow return to normal positive values.

Lightning—A rough estimate in the case of thirteen thunder-clouds gave a mean electrical moment of 1.7×10^{16} e.s.u.-cm. With regard to the usual potential at the place of observation due to storms within one or two kilometers of the electrometer, the negative potentials were almost invariably the greater, but rarely exceeded 1,000 volts per meter.

Typhoon-squalls—Typhoon-squalls may or may not be accompanied by lightning, but in either case it is interesting to note that the potential rarely shows much change until the very coming of the squall. In the usual type of squall, which comes with the southwest wind, there is almost invariably a quick negative drop of potential at the time the rain starts, and the potential remains negative with values ranging from 100 to even 1,000 volts per meter as long as the squall lasts. There is then usually a slow return to normal, lasting sometimes an hour or two. Hence on days when the typhoon has passed somewhat to the north of the city and squalls during the day are quite frequent, the potential may remain negative for almost the whole day. The squalls accompanied by thunder and lightning seem to imitate the usual thunder-storm oscillations except that the potential rarely shows any change until the dark rain or scud line is almost above the place of observation, when the potential may either rise or fall suddenly. It is difficult to say why there is this variety of initial potential, but the writer is inclined to believe that the large initial positive potential is had when there are dark lower clouds formed by the raining down from above and yet not any rain reaching the ground. At least one storm was watched in which the formation of these dark lower clouds was actually observed before the squall reached the locality. Since the sky is usually thickly overcast with cumulo-stratus, it is difficult or almost impossible to judge what is really happening in the clouds. But if it is permitted to draw a general conclusion from what is occasionally seen when rifts do appear in the lower stratus and also from the occasional brightening up or darkening of the lower stratus, positive values of potential are more generally obtained when the centers of individual cumuli-peaks are overhead, and more decidedly negative values when one is closer to the edges of the cumulus.

Philippine Weather Bureau,
Manila, Philippine Islands

REVIEWS AND ABSTRACTS

(See also page 176)

CONRAD, V., UND L. WEICHMANN: *Ergebnisse der kosmischen Physik.* Erster Band. Leipzig, Akademische Verlagsgesellschaft m. b. H., 1931 (xi+448 mit 243 Abb.). 24 cm. Preis Brosch. M. 44, Geb. M. 46. (Gerlands Beiträge zur Geophysik, erster Supplementband.)

A noticeable tendency in the publication of scientific information, which may doubtless be ascribed to the prodigious strides being constantly made in all fields of research, is the production of encyclopedic handbooks embodying contributions and reports of many specialists in their particular subjects of study. In Germany especially has this been the case, as attested by the many recently-issued handbooks in all branches of science. To the Leipzig firm responsible for the publication of the monumental Wien-Harms Handbuch der Experimentalphysik, we are now indebted for a similar compilation dealing with cosmical physics, the first volume of which has appeared. This volume contains no preface or introduction and no information is given us regarding the proposed number of volumes to be issued or the precise scope of the work.

The first contribution is furnished by Carl Störmer and deals with the problems connected with the investigation of polar lights, in which the forms and occurrence of the aurora, problems in connection with photographing auroras, their observation, and altitude measurements are discussed in detail. Problems arising in connection with the corpuscular theory are reviewed and general mathematical considerations set forth. Other problems of cosmical nature considered by Störmer are: The Eschenhagen-waves of terrestrial magnetism and the periodic electron-paths in theory and experiment; solar magnetism and coronal structure; emission of corpuscular waves from the Sun; penetrating-radiation; short-wave echoes which occur several seconds after the principal signal; problems of the upper atmosphere, etc. A consideration of the material presented, which may be regarded as constituting a summary of the present status of the author's auroral investigations, indicates that there are many problems of interest to astronomers and meteorologists, as well as to physicists, still awaiting satisfactory solution.

The two following sections by W. Kolhörster and L. Tuwim are devoted to the subject of the penetrating-radiation (Höhenstrahlung), dealing respectively with the barometer-effect and the coefficients of absorption. In the first section a description of methods and instruments, accompanied with good illustrations, and a considerable discussion of results thus far obtained are given. In the second section, a general discussion of methods, instruments, and observational data, is followed by a useful reference table summarizing the coefficients of absorption of the penetrating-radiation in air, water, lead, and gold, as obtained by different investigators. In view of the importance of the transition-effect on the determination of the coefficients of absorption, somewhat greater emphasis on this puzzling phenomenon would have been desirable in a discussion of this kind. In both sections the work of the authors, who have given much study to the subject, plays a large part.

A full and well-balanced summary of the present status of our knowledge of atmospheric ozone is contributed by F. W. Götz. The remainder of the work consists of contributions on the propagation of explosion waves in the Earth's atmosphere, by P. Duckert, new methods of determining the figure of the Earth, by F. Hopfner, and the dynamics of forms of motion (water, sand, etc.) on the Earth's surface, by the late F. M. Exner.

H. D. HARRADON

FINAL RELATIVE SUNSPOT-NUMBERS FOR 1931

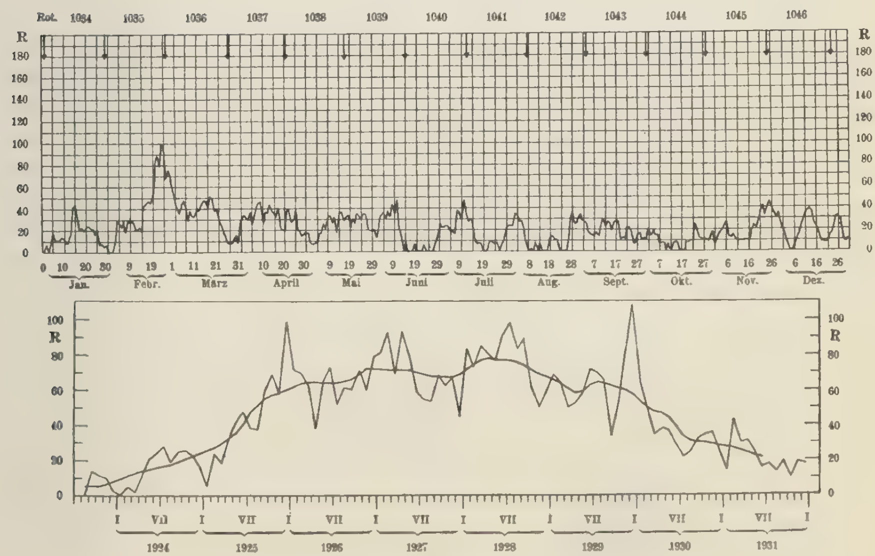
BY W. BRUNNER

The following Tables contain the final relative sunspot-numbers for 1931, for the whole disc of the Sun, based on observations made at the Zurich Observatory, supplemented by series furnished by other co-operating observatories for days (indicated by asterisks) where no observations were possible at Zurich.

Table 1 gives the yearly mean of the relative numbers, R, since the last minimum 1923 and of the number of days without spots.

TABLE 1—*Yearly means of relative sunspot-numbers, R*

Year	R	Increase	No. spotless days
1923	5.8	......	200
1924	16.7	+10.9	116
1925	44.3	+27.6	29
1926	63.9	+19.6	2
1927	69.0	+ 5.1	0
1928	77.8	+ 8.8	0
1929	65.0	−12.8	0
1930	35.7	−29.3	3
1931	21.2	−14.5	43



FIGS. 1 AND 2

TABLE 2—*Final relative sunspot-numbers for the whole disc of the Sun for 1931*

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	0	0	*E*34[c]	34[d]	17	13	22	23[aa]	34	10	8	19
2	7	8	31	32	8	*E*28[c]	23	*ME*35[cc]	27[a]	21	14	15
3	0	28[d]	25[a]	29	7	34	23	34	26	14	*E*17[c]	7
4	9*[d]	27*	33*	37*	8	36	19	28	18	18[a]	18	0*
5	18	23	37*	*E*25[c]	8	30[a]	19[a]	28	15	15	24	0
6	11	29	33*	31	17	36	16	19	14	15	27*	*E* 6[c]
7	11	18	29[a]	41[a]	17[d]	32	*E*38*[c]	8	15	7	13[a]	12
8	12	27[a]	37*	45	26	*M*44[c]	35	0	18	8	12	13
9	14	29	33[d]	46	*M*20[c]	35	28	2*	13	7	16	24
10	11[a]	28	33	29[a]	33	47	*M*48[ac]	0	*E*24[c]	0	0	*E*29[c]*
11	10	20	38	37[d]	33	20	35	8	29	7	0	35[a]
12	9	*E*20[c]	38	36	26	14	26	0	*M*23[c]	0	0	37
13	*M*16[c]	23	43[d]	44[a]	32[a]	0	30	8	27	*M* 8[c]	0	38[a]
14	41	19[cd]	47	38	17	*W*10[c]	23	0	26	9	0	35
15	43	41	46[b]	37	*E*36[c]	0	8	0	19[d]	8	0*	25
16	27	44	41	31[a]	37	0	7	0	27	0	0	22*
17	*E*20*[c]	47*	*W*51[c]	41	29	0	8	*M*11[c]	28	0	8	15
18	22	45	49[a]	22	32*	7	7	14	26	0	14	8
19	19*	50*	38	20[a]	34	0	0	14	11	8[d]	10	8
20	24[a]	64[ab]*	40	20	22*[b]	0	0	10	13*	8	16[d]	8
21	24	89[b]	27	*W*38[c]	*E*30[c]	0	*E* 7[c]	10	10[a]	10	37	8
22	22	79	25	41	26	7	10	0	*M*22[c]	9	41	15
23	21	100	17	27	35	0	8	0*	22	25	33	16
24	16*	92	16[a]	*M*29[c]	32	0	8	0	16	18	40*	22[d]
25	20	68[a]	8	37	31	0	8	0	7	12*	44	31
26	7*	76[d]	8	21	*W*35[c]	0	0	*M* 8[c]	7	11*	*M*42[bc]	30
27	8	67	8	19	35	*E* 8[c]	*E* 7[c]	*M*26[cd]	15	11	35[a]	30
28	5*	47	14	14	20	10	9	36	17[d]	11	31	15
29	7		16	*W*17[c]	19	25[d]	*E*22[c]	25	10	9	35*	9
30	0		9	18	20[d]	23	23	26	11	12*	27	11[a]
31	0*		*WE*27[cc]		20		23	*E*30[c]		*W*18[c]		9
Mean	14.6	43 1	30.0	31.2	24.6	15.3	17.4	13.0	19.0	10.0	18.7	17.8

[a]Passage of an average-sized group through the central meridian.
[b]Passage of a large group or spot through the central meridian.
[c]New formation of a centre of activity: *E* on the eastern part of the Sun's disc; *W* on the western part; *M* in the central circle zone.
[d]Entrance of a large or average-sized centre of activity on the east limb.

Figure 1 gives a graphical representation of the daily relative sunspot-numbers for 1931, the times being plotted as abscissas and the relative numbers as ordinates. The limits of the successive solar rotations are indicated by vertical arrows in the upper edge of the figure. The secondary maxima and minima succeeding the rotation-periods do not represent real fluctuations in sunspot-activity, but are rather to be attributed to the influence of solar rotation, to a certain stability of the centres of activity for spots, and to the special distribution of these centers of activity in the direction of rotation.

Figure 2 shows the observed and smoothed monthly relative numbers for 1923 to 1931 (1923 year of the last sunspot-minimum). The purpose of smoothing is to eliminate the secondary variations. The method of smoothing is as follows: For obtaining the mean of the epoch July 1, the average of the monthly means of the twelve months January to December is taken (m_1), and for the epoch August 1, the average of the monthly means for February to January (m_2). The mean of these $m = (m_1 + m_2)/2$, which represents the smoothed relative number for the middle of July, is used for the construction of the curve.

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ABSTRACT OF SUPPLEMENTARY RESOLUTIONS[1] OF THE INTERNATIONAL COMMISSION FOR THE POLAR YEAR 1932-33

BY H. D. HARRADON

The Sub-Commission for Actinometric Researches during the Polar Year 1932-33, appointed at the Conference of Directors at Copenhagen in 1929, having presented a program for these researches, the International Commission for the Polar Year at its meeting at Leningrad in August 1930, designated Messrs. H. Dominik and A. F. Wangenheim to study the question of actinometric instruments, and the President of the Commission, Dr. D. la Cour, requested these gentlemen to act as a Sub-Committee for this subject. After considering the program, Messrs. Dominik and Wangenheim signified their approval of it. Now that these proposals have also received the approval of the President, they thus become resolutions, Nos. 58-65 of the International Commission for the Polar Year 1932-33. Translations of these as given in the Commission's circular may be summarized as follows:

58. The measurements of the direct solar radiation are to be so organized that in addition to the total depletion by the atmosphere, the turbidity can be computed from them free from selective absorption by water-vapor. For this purpose, it is recommended that filter-glasses of the same composition and thickness be used at all stations. The Potsdam Meteorological Observatory is prepared to procure and calibrate such filters. As regards the nature and use of the filters, reference may be made to the article by Dr. Büttner in the Meteorologische Zeitschrift, **48**, 170-171 (1931).

59. Since the investigations regarding the fixing of a standard scale for pyrheliometric measurements are not yet completed, it is recommended that all measurements be provisionally referred to the Smithsonian scale of 1913. Instruments which are

[1]For previous resolutions see Terr. Mag., **35**, 245-248 (1930), and **36**, 324-332 (1931).

calibrated according to the Ångström scale can be changed to the Smithsonian scale by the addition of 3.5 per cent.

It is recommended that the standard pyrheliometers used during the Polar Year be calibrated both before and after the expedition, and that this be done at one of the following places: Upsala, Potsdam, or Washington. In order to be able later to eliminate the vitiating effect of the light from the sky in measurements of the direct solar radiation, it is necessary to give, in addition to the type of instrument used, information, as accurately as possible, pertaining to the aperture of the actinometer (length of tube, size of outer and inner diaphragms, or size of absorbing surface).

60. It is recommended that measurements of the total incoming radiation and of effective outgoing radiation be made at favorably situated stations where sufficient scientific assistance is available. Instruments used for this purpose are also to be referred to the standard apparatus. Proposals for carrying out such measurements have been prepared by Dr. Albrecht, Potsdam.

61. The value of measurements of clearness of the atmosphere, abnormal refraction (dip-of-horizon measurements), twilight, light from night sky, and zodiacal light is pointed out. Particulars regarding the nature of these measurements have been worked out by Professor Maurer, Zurich, and Dr. F. Schmid, Oberhelfenwil.

62. For eye-observations of quantity and character of the opalescent atmospheric turbidity, reference is provisionally made to special instructions by Dr. Bergeron in Geofysiske Publikasjoner, Oslo, **5**, No. 6, 103-107 (1930).

63. As the value of the constant of radiation of the Stefan-Boltzmann formula, the value 8.26×10^{11} cal/cm^2 T^4 (5.76×10^{-12} watt/cm^2 T^4) is recommended.

64. With reference to the plan of actinometric measurements and their summarization for publication, reference is made to the tables of intensity of solar radiation in North and Central Europe, prepared by the Meteorologisch-Magnetisches Observatorium in Potsdam. Measurements of the total and filtered radiation should be made according to the scheme there given.

It is recommended to carry out, if possible, other actinometric determinations, as nearly simultaneously as possible with the above-mentioned fundamental measurements of the direct radiation. For these other measurements a definite program cannot be drawn up, but it is recommended that the observer in question be left free to carry them out in connection with his individual problems.

65. With regard to symbols for actinometric factors, reference may be made to the article by Dr. Ångström in the Monthly Weather Review, **59**, 354 (1931).

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LETTERS TO EDITOR

PROVISIONAL SOLAR AND MAGNETIC CHARACTER-FIGURES, MOUNT WILSON OBSERVATORY, JANUARY, FEBRUARY, AND MARCH, 1932

In addition to the following magnetic storms, in which the total range in H exceeded 100γ, two storms of slightly less intensity were recorded on February 19 and 20, and March 18, respectively.

Greenwich mean time						Range hor. int.
Beginning			Ending			
1932	*h*	*m*	*d*	*h*	*m*	γ
Feb. 2	20	..	5	7	..	134
Mar. 28	0	..	2	23	..	130
Apr. 7	2	..	8	19	..	123

No solar observations were made at Mount Wilson from January 30 to February 3, inclusive. On February 4 the only spot observed was a small one, 40° west of the central meridian. The hydrogen spectroheliograms on that date showed no unusual activity.

No solar observations were made at Mount Wilson from February 13 to 18, inclusive. No spots were observed on February 19 and 20, and the hydrogen spectroheliograms showed no activity on these dates.

On March 18 a small group was observed 35° east of the central meridian, accompanied by no more than the normal amount of hydrogen activity.

A regular unipolar spot crossed the central meridian on March 31.5, G.M.T., 19° north of the center of the disc. The region of the small bipolar group in which spots were last seen on March 28 remained active during the storm of March 28 to April 2. It passed within 2° of the center of the disc on March 29.9, G.M.T., and probably contributed more to the storm than the larger, less active spot.

On April 7 no spots were visible and the spectroheliograms showed no areas with special activity.

Sudden changes in H were recorded as shown in the following table.

Greenwich mean time				Direction of change
1932		*h*	*m*	
Feb.	7	9	49	Increasing
Mar.	18	0	46	Increasing
Apr.	22	5	29	Increasing
Apr.	22	11	08	Decreasing

Day	January 1932 K_2 A	K_2 B	$H\alpha B$ A	$H\alpha B$ B	$H\alpha D$ A	$H\alpha D$ B	No. groups	Mag'c char.
1	...	...	2	2	0.5	0	2	0.5
2	...	...	1.5	0.5	1	0	3	1.0
3	...	...	...	...	...	...	3[a]	0.5
4	1.5	1	1	1	1	0	2	0
5	1	1	1	1	0.5	0	2	0
6	1	1	1	1	0.5	0	1	0
7	1	2	1.5	2	0.5	1.5	0	0.5
8	...	...	...	...	...	...	1	1.0
9	1	1	1	1	0.5	1	1	0.5
10	1	0.5	1	0	0.5	0	0	0.5
11	0	0	0.5	0	0.5	0	1	1.0
12	...	...	...	...	...	...	...	0.5
13	...	...	...	...	...	...	...	0.5
14	...	...	...	...	...	...	1[c]	0.5
15	...	...	...	...	...	...	...	0.5
16	...	...	...	...	...	...	2	0.5
17	1	0	1	0	1	0	2	0
18	0.5	0.5	1	0	1	0.5	1	0
19	0.5	0.5	1	0.5	1	2	1	0
20	0.5	0.5	0.5	0.5	2	1	2	0
21	0	0	0.5	0	2	1	1	0
22	0.5	0	0.5	0	1	0	2	0
23	1	0	1	0	1	0	2	0
24	1	0.5	1	0.5	1	0	2	0.5
25	1	1	1	1	0.5	0	3	1.0
26	...	...	...	...	...	...	5	0.5
27	...	...	...	...	...	...	4[a]	1.0
28	1	1	1	0.5	0	0	2	1.0
29	1	0	1	0	0.5	0	2	0.5
30	...	...	...	...	...	...	...	0.5
31	...	...	...	...	...	...	...	0.5
Mean	0.8	0.6	1.0	0.6	0.8	0.4	1.8	0.4

Day	February 1932 K_2 A	K_2 B	$H\alpha B$ A	$H\alpha B$ B	$H\alpha D$ A	$H\alpha D$ B	No. groups	Mag'c char.
1	...	...	...	...	...	...	...	0
2	...	...	...	...	...	...	...	0.5
3	...	...	...	...	...	...	...	1.5
4	0	0	0	0	0	0	1	1.0
5	...	...	...	...	...	...	1	0.5
6	...	...	...	...	...	...	...	0.5
7	...	...	...	...	...	...	...	0.5
8	...	...	...	...	...	...	...	0.5
9	...	...	...	...	...	...	...	0.5
10	...	...	...	...	...	...	1[c]	1.0
11	0	0.5	0.5	1	1	0	1	0.5
12	0	0.5	0.5	1	1	0	1	0.5
13	...	...	...	...	...	...	...	0.5
14	...	...	...	...	...	...	...	0.5
15	...	...	...	...	...	...	...	0
16	...	...	...	...	...	...	...	0
17	...	...	...	...	...	...	...	0
18	...	...	...	...	...	...	...	0
19	0	0	0	0	1	0	0	1.0
20	0	0	0	0	0.5	0	0	1.0
21	0	0	0	0	0	0	0	0.5
22	0	0	0	0	0.5	0	0	0.5
23	0.5	1	0.5	0.5	0.5	0	3	1.0
24	1	1	1	1	0	0	3[a]	0.5
25	1	1.5	1	2	0	0	1	0.5
26	2	2	2	2	0	0	1	0
27	2	2	2	2	0	0	2[b]	0
28	2	2	2	2	0	0	2	0
29	2	0	2	0	0	0	2	0
30								
31								
Mean	0.8	0.8	0.8	0.8	0.3	0.0	1.2	0.5

Day	March 1932 K_2 A	K_2 B	$H\alpha B$ A	$H\alpha B$ B	$H\alpha D$ A	$H\alpha D$ B	No. groups	Mag'c char.
1	2	1	2	0	0	0	5	0
2	2	1	2	1	0.5	0	5	0.5
3	...	...	...	...	...	...	...	1.0
4	1	2	1	2	0.5	1	2	1.0
5	1	2	2	2	0	0	2	1.0
6	1.5	1	2	1	0.5	0	2	0.5
7	1.5	1	2	1	0.5	0	1	0.5
8	...	...	...	...	...	...	1	0.5
9	1	0	1	0	0	0	1	1.5
10	...	...	1[d]	0[d].5	0[d]	0[d]	0	1.0
11	0	0.5	0.5	0.5	0.5	0	0	1.0
12	0	0.5	...	...	...	...	0	0
13	...	...	...	...	...	...	0	0.5
14	...	...	0	0	0	0	0	0.5
15	0	0	...	...	...	...	0	0
16	0	0	0	0	0	0	1	0
17	0	0	0	0	0.5	0	1	0
18	0	0	0	0	0.5	0	1	1.0
19	1	1	0.5	0.5	1	0	1	0
20	...	...	...	...	...	...	...	0.5
21	1	1	1	1	0.5	0	1	1.0
22	1	1	1	1	0	0	1	1.0
23	1	1	1	1	1	1	0	0.5
24	0.5	1	1	1	1	0.5	0	0.5
25	0.5	1	1	1	1	0	1	0
26	1	0.5	1	1	1	0	2	0
27	1	0	1	0	0.5	0	2	0
28	1	1	1	1	0	0	2	1.0
29	1	1	1	1	0	0	1	1.0
30	1	1.5	1	1	0	0	1	2.0
31	1	1	1	1.5	0.5	0	1	1.5
Mean	0.8	0.8	1.0	0.8	0.4	0.1	1.2	0.6

[a]Passage of a small group through the central meridian within 10° of the center of the disc. [b]Passage of an average-sized group through the central meridian within 10° of the center of the disc. [c]Passage of a small group through the central meridian within 5° of the center of the disc. [d]Low weight.

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Seth B. Nicholson
Elizabeth E. Sternberg

AMERICAN *URSI* BROADCASTS OF COSMIC DATA[1]

Kennelly-Heaviside Layer heights, Washington, D. C., February to April, 1932

Date	Frequency	Nearest hour G.M.T.	Height
1932	*kc/sec*	*h*	*km*
Feb. 2	6,250	20	No value obtained
" "	6,000	20	390, 660
" "	5,000	21	260, 390
" "	4,100	21	250
" "	3,450	21	220
" "	3,000	21	220
" "	1,600	21	120
" 10	1,600	20	No value obtained
" "	2,000	20	110
" "	3,000	21	240
" "	3,450	21	250
" "	4,100	21	250
" "	5,050	21	250
" "	5,500	21	250
" "	5,900	21	270
" "	7,500	19	350
" "	7,700	19	470
" "	8,000	19	740
" "	8,100	19	No value obtained
" 16	5,900	19	330
" "	1,600	20	No value obtained
" "	2,000	20	120
" "	2,200	20	140
" "	2,500	20	120
" "	2,600	20	160
" "	2,700	20	130, 210
" "	2,650	21	210
" "	3,000	21	200
" "	3,450	21	240
" "	4,100	21	250
" "	5,050	21	280
" 23	8,000	19	No value obtained
" "	6,900	19	840
" "	6,800	19	750
" "	6,500	19	310
" "	5,900	19	270
" "	1,600	19	120
" "	2,000	19	120
" "	2,500	20	120
" "	2,650	20	140
" "	3,000	20	250
" "	4,100	21	250
" "	5,050	21	250
Mar. 1	6,600	18	No value obtained
" "	6,500	18	420
" "	6,000	18	290
" "	5,500	18	290
" "	5,000	19	250
" "	4,000	19	250
" "	3,500	19	110, 210
" "	3,000	19	110, 200, 250
" "	2,600	20	110
" "	2,500	20	No value obtained
" 9	8,500	18	" " "
" "	8,200	18	800
" "	8,000	19	800
" "	7,500	19	800
Mar. 9	7,000	19	310
" "	6,000	20	290
" "	5,000	20	260
" "	4,500	21	250
" "	4,100	21	250
" "	3,000	21	210
" "	2,000	21	130
" 16	6,120	20	No value obtained
" "	6,100	20	110
" "	5,900	20	510
" "	5,500	20	350
" "	5,000	20	330
" "	4,500	20	250
" "	3,400	20	140, 240
" "	3,000	20	130, 200
" "	2,500	20	140
" 22	3,450	21	270
" "	4,100	21	300
" "	4,500	21	330
" "	4,800	21	340
" "	5,000	21	370
" "	5,200	21	440
" "	5,300	21	480
" "	5,350	21	No value obtained
Apr. 1	6,700	19	" " "
" "	6,650	19	470
" "	6,250	19	340
" "	6,000	19	330
" "	5,000	20	110, 290
" "	4,500	20	140, 260
" "	3,450	20	120, 230
" "	3,000	20	120, 230
" "	2,800	20	130
" 7	6,100	18	No value obtained
" "	6,050	18	830
" "	5,900	18	430, 500
" "	5,500	18	380
" "	4,500	18	110, 270, 360
" "	3,450	18	150, 290, 370
" "	2,900	18	120, 220
" "	2,700	18	120
" 14	5,020	19	No value obtained
" "	5,000	19	910
" "	4,970	19	780
" "	4,800	19	710
" "	4,500	19	290, 810
" "	4,300	20	140, 270, 420
" "	4,200	20	140, 390
" "	3,800	20	140, 350
" "	3,400	20	120
" "	3,000	20	120
" "	2,700	20	No value obtained
" 21	5,800	18	" " "
" "	5,770	18	490
" "	5,400	18	400
" "	5,000	19	340, 480
" "	4,600	19	250, 350

[1] For previous announcements see Terr. Mag., **35**, 184-185 and 252-253 (1930); **36**, 54, 141, 258-259, and 358-360 (1931); **37**, 85-89 (1932).

Kennelly-Heaviside Layer heights, Washington, D. C., February to April, 1932 (Concluded)

Date	Frequency	Nearest hour G.M.T.	Height	Date	Frequency	Nearest hour G.M.T.	Height
1932	*kc/sec*	*h*	*km*	*1932*	*kc/sec*	*h*	*km*
Apr. 21	3,800	19	110, 240	Apr. 27	5,000	19	520
" "	3,400	19	110, 240	" "	4,600	19	280, 440
" "	3,000	19	110	" "	4,000	19	250
" "	2,700	19	No value obtained	" "	3,600	19	110, 220
" 27	5,600	19	" " "	" "	3,000	19	120
" "	5,500	19	520	" "	2,800	19	No value obtained

The data for terrestrial magnetism, sunspots, solar constant, and aurora are the same as given in previous tables.

The first three columns of the Table give (1) the magnetic character according to the scale 0-2 of the International Commission of Terrestrial Magnetism and Electricity, (2) the type featuring the day other than normal by the letters *b*, *p*, *o*, and *i* for days marked by bay, rapid pulsa-

Summary American URSI daily broadcasts of

Date	February																March						
	Magnetism			Sunspot		Solar constant		Aurora									Magnetism			Sunspot		Solar constant	
	Char.	Type	G. M. T. begin. distur.	Groups	No.	Value	Char.	Char.	Duration	Cloudiness	Form without rays	Form with rays	Area covered	Av. altitude	Position	G.M.T. greatest distur.	Char.	Type	G. M. T. begin. distur.	Groups	No.	Value	Char.
			h m			*cal**			*hrs*					°		*h*			*h m*			*cal*	
1	0	..	.. ....	...	...	......	..	9	...	10	.....	.....	...	...	....	...	0	..	.. ....	5	17	1.946	*f*
2	0	..	.. ....	...	...	......	..	1	5	8	*HA*	*RB*	0.2	25	*NW-N-E*	9	0	..	.. ....	5	18	1.946	*u*
3	1	*i*	5	...	...	......	..	9	...	10	.....	.....	...	...	....	...	2	*p*	.. ....	...	...	1.943	*f*
4	1	*i*	.. ....	1	1	......	..	1	1	7	*DS*	*RB*	0.2	40	*W-N-E*	14	2	*i*	.. ....	2	9	1.944	*f*
5	1	*i*	.. ....	1	1	......	..	1	2	9	*HA*	.....	0.2	7	*N-NE*	10	1	*i*	.. ....	2	5	1.936	*u*
6	0	..	.. ....	...	...	......	..	2	8	1	*HV*	*RF*	0.6	45	*W-N-E*	13	1	*i*	.. ....	2	9	......	..
7	1	*i*	.. ....	...	...	......	..	1	7	2	*HV*	*RV*	0.6	35	*NW-NE-E*	12	1	*p*	.. ....	1	5	......	..
8	0	..	.. ....	...	...	......	..	1	3	4	*HB*	.....	0.2	35	*W-N-E*	9	1	*i*	.. ....	1	4	......	..
9	1	*p*	.. ....	...	...	......	..	1	7	1	*HV*	*R*	0.4	75	*NW-NE-E*	11	1	*i*	.. ....	1	1	1.940	*u*
10	1	*i*	.. ....	1	1	......	..	3	9	1	*HV*	*RV*	0.6	80	*NW-NE-E*	15	2	*i*	.. ....	1	1	1.945	*u*
11	1	*p*	.. ....	1	5	......	..	1	8	1	*HV*	.....	0.4	75	*W-NE-E*	13	2	*i*	.. ....	0	0	......	..
12	1	*i*	.. ....	1	2	......	..	1	9	1	*HA*	.....	0.6	75	*W-NE-SE*	10	0	..	.. ....	0	0	1.956	*f*
13	0	..	.. ....	...	...	......	..	9	...	10	.....	.....	...	...	....	...	0	..	.. ....	0	0	......	..
14	0	..	.. ....	...	...	......	..	1	3	7	*HV*	.....	0.2	80	*NW-NE-E*	11	0	..	.. ....	0	0	1.953	*f*
15	0	..	.. ....	...	...	......	..	9	...	10	.....	.....	...	...	....	...	0	..	.. ....	0	0	1.951	*f*
16	0	..	.. ....	...	...	......	..	9	...	10	.....	.....	...	...	....	...	0	..	.. ....	1	1	1.945	*s*
17	0	..	.. ....	...	...	......	..	9	...	10	.....	.....	...	...	....	...	0	..	.. ....	1	2	1.956	*s*
18	0	..	.. ....	...	—	......	..	1	1	1	*HA*	*R*	0.2	20	*N-NE-E*	9	1	*i*	0 45	1	5	1.959	*f*
19	0	..	.. ....	0	0	......	..	9	...	10	.....	.....	...	...	....	...	1	*p*	.. ....	...	...	1.959	*f*
20	1	*i*	.. ....	0	0	......	..	1	4	0	*HV*	*RV*	0.6	85	*W-N-E*	8	0	..	15 30	...	...	......	..
21	0	..	.. ....	...	...	......	..	1	1	1	*HA*	.....	0.2	45	*NW-N-E*	12	1	*i*	.. ....	1	2	......	..
22	0	..	.. ....	0	0	......	..	1	5	0	*HV*	*RV*	0.4	60	*NW-NE-E*	9	1	*i*	.. ....	1	1	1.948	*f*
23	0	..	.. ....	3	10	......	..	0	...	0	.....	.....	...	...	....	...	1	*i*	.. ....	...	...	1.953	*s*
24	1	*p*	.. ....	3	14	......	..	1	8	0	*HV*	*RV*	0.4	75	*NW-NE-E*	9	0	..	.. ....	...	...	1.956	*s*
25	0	..	.. ....	...	...	......	..	1	5	3	*HA*	.....	0.2	25	*W-NE-E*	9	0	..	.. ....	0	0	1.956	*f*
26	0	..	.. ....	1	21	......	..	1	5	3	*HV*	*RV*	0.2	20	*NW-NE-E*	12	0	..	.. ....	1	1	1.956	*s*
27	0	..	.. ....	2	17	......	..	1	3	3	*DS*	.....	0.2	15	*N-NE*	7	0	..	.. ....	2	4	1.948	*s*
28	0	..	.. ....	2	17	1.949	*f*	1	3	2	*HA*	.....	0.2	20	*NW-NE-E*	15	1	*b*	0	2	4	......	..
29	0	..	.. ....	2	11	1.950	*s*	1	3	3	*HA*	.....	0.2	30	*NW-NE-E*	9	2	*i*	.. ....	1	1	1.961	*u*
30																	2	*i*	.. ....	1	1	1.957	*f*
31																	2	*i*	.. ....	1	1	......	..
Mean	0.3			1.3	7.1			1.1	5	4		..	..	.	...	11	0.8			1.3	3.5	1.951	

Greenwich mean time for endings of storms: 7^h, Feb. 5; 1^h, Feb. 11; 11^h, Mar. 5; 12^h, Mar. 8; 10^h, Mar. 11; 5^h,

*Due to instrument damage at Chile station, solar constants are temporarily omitted.

tions, long-period oscillations, and irregular oscillations, respectively, and (3) the hour and minute of Greenwich mean time marking the beginning of a storm, the end of the storm being indicated in the footnote to the Table. The next two columns give the data relating to sunspots: (1) the number of groups of spots and (2) the total number of spots. It is to be noted that sunspot-numbers such as those from Zürich can be obtained from the number of groups and spots given in the Table by the formula $N=k\ (10g+s)$, where k for Mount Wilson is about 0.77. The sixth and seventh columns show (1) the value in calories of the solar constant, and (2) by letters s, f, and u, whether the determination was satisfactory, fair, or unsatisfactory, respectively.

Under the general heading of aurora in the table, the first column gives the character of the day: 0 indicates no aurora; 1, faint; 3, moderate; 5, strong; 7, brilliant; and 9, no observation or no observations possible on account of cloudiness. The second column gives the number of hours during which aurora was present. The third column indicates the amount of sky covered by cloud on a scale of 0-10, where 0 means cloudless, and 10 completely overcast.

smic data, February to April 1932

March									April																		
Aurora									Magnetism				Sun-spot		Solar constant		Aurora										Date
	Duration	Cloudiness	Form: with-out rays	Form: with rays	Area covered	Av. altitude	Position	G.M.T. greatest distur.	Char.	Type	G. M. T. begin. distur.		Groups	No.	Value	Char.	Char.	Duration	Cloudiness	Form: with-out rays	Form: with rays	Area covered	Av. altitude	Position	G.M.T. greatest distur	
	hrs					°		h			h	m			cal.			hrs					°		h	
	6	2	HA	RB	0.4	20	NW-N-E	13	1	i	..	....	1	1	1.967	f	1	5	4	HV	.....	0.2	35	NW-N-E	9	1
	2	2	HA	R	0.4	30	NW-NE-E	13	2	i	..	....	2	2	1.941	u	3	8	4	HV	RV	0.6	5	NW-N-E	10	2
3	9	2	HV	RV	0.6	85	W-N-E	12	1	i	..	....	1	2	1.964	f	1	2	8	HA	.....	0.2	45	NW-N-E	11	3
	8	0	HV	.....	0.6	75	NW-N-E	13	1	i	..	....	2	3	1.957	u	9	...	10	.....	.....	...	...	....	...	4
1	10	1	HV	R	0.6	50	NW-NE-E	9	1	i	..	....	1	1	.....	..	1	5	1	HV	RV	0.2	25	NW-N-E	13	5
3	7	3	HV	RB	1.0	65	NW-E-A	12	1	i	..	....	0	0	1.941	u	1	4	5	HA	.....	0.2	30	NW-N-E	8	6
1	1	9	G	.....	0.2	50	NW-N-E	12	1	i	..	....	0	0	.....	..	3	8	1	HV	RV	0.6	75	W-N-E	10	7
1	5	5	HV	R	0.4	40	NW-N-E	11	1	i	..	....	0	0	.....	..	1	5	2	HV	RV	0.6	20	NW-N-E	8	8
3	9	1	HV	RV	0.8	65	NW-N-E	12	0	..	..	....	...	...	1.947	f	1	3	6	HV	RV	0.2	45	NW-N-E	11	9
3	9	1	HV	RV	0.6	70	NW-N-E	10	0	..	..	....	1	2	1.957	f	1	4	5	HV	.....	0.2	25	NW-N-E	9	10
1	1	9	HA	.....	0.2	45	NW-N-E	9	0	..	..	....	1	3	1.963	s	1	1	3	HA	.....	0.2	15	NW-N-NE	11	11
1	9	4	HV	RV	0.4	35	NW-N-E	10	0	..	..	....	1	1	1.958	f	1	1	3	HA	.....	0.2	20	NW-N-NE	12	12
1	7	1	HA	.....	0.4	60	NW-N-E	10	0	..	..	....	...	...	1.967	f	1	3	1	HV	RV	0.2	20	NW-N-E	10	13
1	7	1	HV	R	0.4	60	NW-N-E	10	2	p	..	....	...	...	1.962	s	2	4	0	HV	RV	0.4	60	NW-N-E	8	14
9	...	10	.....	.....	...	...	....	...	1	i	..	....	1	4	1.966	s	1	4	1	HV	RV	0.4	80	NW-N-E	10	15
1	3	5	HA	.....	0.2	25	N-NE-E	9	0	..	..	....	1	2	1.964	u	1	3	3	HV	RV	0.4	25	NW-N-E	10	16
1	1	7	HA	.....	0.2	25	N-NE-E	10	0	..	..	....	1	2	1.955	f	1	2	3	HV	RV	0.4	35	NW-NE-E	10	17
1	3	2	HV	RV	0.4	80	NW-NE-E	10	1	i	..	....	1	2	.....	..	1	1	1	HV	RV	0.4	40	W-N-E	10	18
9	...	5	.....	.....	...	...	....	...	1	i	..	....	...	...	1.951	f	1	2	3	HA	.....	0.2	25	N-NE-E	9	19
1	1	6	HA	.....	0.2	25	NW-N-NE	10	0	..	..	....	...	...	1.943	u	1	3	0	HA	.....	0.2	30	NW-N-E	12	20
3	7	1	G	RF	0.2	75	NW-NE-E	9	0	..	..	....	2	7	1.952	s	1	1	1	HA	.....	0.2	10	N-NE-E	10	21
3	7	1	G	RF	0.4	75	NW-NE-E	9	1	p	5	30	2	12	1.954	s	1	1	6	HA	.....	0.2	45	NW-N-E	11	22
1	1	9	.....	RB	0.2	12	NW-N-NE	12	1	i	..	....	...	...	1.956	s	3	2	6	HV	RV	0.6	45	NW-N-E	11	23
1	1	9	HA	.....	0.2	20	NW-N-NE	10	1	o	..	....	...	...	1.938	u	1	4	0	HV	RV	0.6	45	NW-N-E	9	24
1	4	7	HA	.....	0.2	20	NW-N-E	9	1	i	..	....	...	...	1.948	u	1	1	3	.....	RV	0.4	30	NW-N-E	7	25
9	...	10	.....	.....	...	...	....	...	1	i	..	....	...	...	.....	..	1	1	3	HA	.....	0.2	90	NW-N-E	11	26
1	2	6	G	.....	0.2	30	NW-N-NE	13	1	i	18	....	1	11	.....	..	1	1	1	.....	RV	0.2	75	NW-N-E	9	27
3	8	8	G	.....	0.4	75	NW-N-E	11	1	i	..	....	1	13	.....	..	0	...	2	.....	.....	...	...	....	...	28
5	6	6	G	RF	1.0	85	W-N-E	12	0	..	..	....	1	11	.....	..	1	1	3	HA	.....	0.6	80	NW-NE-E	8	29
1	8	3	G	RF	0.4	60	NW-N-E	9	0	..	..	....	1	3	.....	..	0	...	1	.....	.....	...	...	....	...	30
1	6	5	G	RF	0.4	35	NW-N-E	12																		31
.6	5	4	.....	.....	...	...	....	11	0.7	.	..	....	1.0	3.9	1.955	..	1.2	3	3	.....	.....	...	...	....	10	Mean

Iar. 19; 4^h, Mar. 28; 9^h, April 14; $10^h\ 30^m$, April 27; 10^h, April 28.

Columns four and five describe by letters the form of the aurora, column four indicating forms without ray structure and column five, forms with ray structure. The letters employed are the same as those used in the Photographic Atlas of Auroral Forms published by the International Geodetic and Geophysical Union, Oslo, 1930, so far as it was possible to use those letters. For forms without ray structure *HA* indicates homogeneous quiet arcs; *HB*, homogeneous bands; *PA*, pulsating arcs; *DS*, diffuse luminous surfaces; *PS*, pulsating surfaces; *G*, feeble glow; *HV*, varied forms; *HF*, flaming aurora, and *HVF*, varied forms with flaming. For forms with ray structure *RA* indicates arcs; *RB*, bands; *D*, draperies; *R*, rays; *C*, corona; *RV*, varied forms; *RF*, flaming aurora; and *RVF*, varied forms with flaming.

Column six gives the maximum area of sky covered in tenths of the whole sky, column seven the average altitude in degrees, and column eight the general position of the aurora, being reckoned for included positions in a clockwise direction with *Z* representing zenith and *A* the whole sky. The final column gives the Greenwich mean hour of the observed greatest display in the preceding 24 hours of the Greenwich day.

The table of Kennelly-Heaviside Layer heights is self-explanatory.

DEPARTMENT OF TERRESTRIAL MAGNETISM, CARNEGIE INSTITUTION OF WASHINGTON, *Washington, D. C.* KATHARINE B. CLARKE

PROVISIONAL SUNSPOT-NUMBERS FOR MARCH TO MAY, 1932

(Dependent alone on observations at Zürich Observatory and its station at Arosa)

Day	Mar.	Apr.	May	Day	Mar.	Apr.	May
1	34	8	8	17	..	9	41
2	46	8	0	18	..	8	40
3	37	16	0	19	9	0	27[a]
4	24[a]	9	0	20	7	0	38[d]
5	22	0	0	21	7	*WE*18[ce]	30
6	22	0	0	22	7	34	31[a]
7	16	0	8[d]	23	0	29	31
8	..	0	..	24	7	..	34
9	..	0	14	25	0	31[b]	23
10	8	0	8	26	8	31	22[a]
11	0	0	9	27	15	32	18
12	0	0	9	28	8	27	17
13	0	0	8	29	8	24	..
14	0	0	*E* 25[ac]	30	8	14	10
15	0	8	36	31	7		8
16	0	8	35[d]				
				Means	11.1	10.8	18.3
				No. days	27	29	29

Mean for quarter January to March, 1932; 11.5 (83 days)

[a]Passage of an average-sized group through the central meridian.
[b]Passage of a larger group through the central meridian.
[c]New formation of a large or average-sized center of activity; *E*, on the eastern part of the Sun's disc; *W*, on the western part; *M*, in the central zone.
[d]Entrance of a large or average-sized center of activity on the east limb.

Zürich, Switzerland W. BRUNNER

PRINCIPAL MAGNETIC STORMS

Sitka Magnetic Observatory

January to March, 1932[1]

(Latitude 57° 03′.0 N.; longitude, 135° 20′.1 or 9^h 01^m.3 W. of Gr.)

Greenwich mean time						Range		
Beginning			Ending			Decl'n	Hor. int.	Ver. int.
1932	*h*	*m*	*d*	*h*	*m*	′	γ	γ
Feb. 3	5	..	5	13	..	74.0	544	410
Mar. 20	23	34	22	15	..	57.2	362	481
Mar. 27	17	49	31	14	..	98.1	419	557

There were no large magnetic storms during this quarter.

February 3-5, 1932—This was a small storm with no particular periods of large activity or rapid oscillations.

March 20-22, 1932—This was a small storm and although the above beginning time showed a definite jog in all of the elements there was only slight activity before this. From 3^h to 14^h on March 22 the *D*-curve was featured by a number of irregular long-period oscillations.

March 27-31, 1932—A small sharp jog marked the beginning in each of the curves and there is only very small activity for nearly a day. There was a period of moderate activity between 16^h and 18^h on March 28. There was another period of moderate activity between 8^h and 14^h on March 29 and a period of greater activity between 5^h and 13^h on March 31. Between these periods the activity was rather small.

Franklin P. Ulrich, *Observer-in-Charge*

Cheltenham Magnetic Observatory

January to March, 1932[1]

(Latitude 38° 44′.0 N.; longitude 76° 50′.5 or 5^h 07^m.4 W. of Gr.)

There were no magnetic storms recorded during the first quarter of 1932.

[*Preliminary note on storm, May 29-30, 1932* —The first really large magnetic storm of the year 1932 was recorded at Cheltenham from 12^h 00^m (G.M.T.), May 29, to 8^h, May 30. The ranges in *D*, *H*, and *Z* were 60′, 484γ, and 450γ, respectively, the chief features were from 22^h (G.M.T.), May 29, to 7^h, May 30. Auroral displays were visible at the Cheltenham Magnetic Observatory May 30 from 1^h 30^m (G.M.T.) when there was a faint glow which developed into a distinct arc at 3^h of elevation 10°–15° and extended over 90° horizontally.]

Geo. Hartnell, *Observer-in-Charge*

[1]Communicated by R. S. Patton, Director, United States Coast and Geodetic Survey.

NOTES

13. *Proposed magnetic work in Haiti*—We have learned from the Engineer in Chief, at Port-au-Prince, that it is the intention of his bureau to establish magnetic stations for declination-observations in the principal towns of Haiti in the very near future.

14. *Magnetic station at Forte Castellaccio (Genoa)*—We have noted with interest from the resolutions passed at the first meeting of the Italian Commission for the Second Polar Year (February 10, 1932), as reported in *L'Universo*, Florence, that a permanent magnetic station established at Forte Castellaccio under the auspices of the Ministerio di Marina, will soon be in regular operation. It will, accordingly, be functioning during the International Polar Year 1932-33 and will coordinate its program with that of the other magnetic stations participating in this world-wide enterprise.

15. *Magnetic station at Point Barrow*—Through cooperation of the United States Weather Bureau, the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, the United States Navy, the United States Coast Guard, and the International Commission for the Second Polar Year, arrangements have been made to obtain magnetic observations and low sensitivity magnetograms during 1932-33 at Point Barrow, Alaska. C. J. MacGregor of the United States Weather Bureau will be in charge. Meteorological, upper-air, and auroral observations will also be included in the observational program.

16. *Summer courses in geophysical prospecting*—The Department of Geophysics of the Colorado School of Mines is offering again this year a short course in geophysical prospecting during the summer. It will consist of a résumé of torsion-balance, magnetic, seismic, and electrical methods of prospecting. Fundamental principles and the present-day practice of field observation and interpretation will be equally stressed. For each of the above methods, the fundamental physical principles, the rock properties and their determinations, theory and description of instruments, theory and practice of interpretation, and description of typical results will be treated. The laboratory work will consist of determinations of the physical properties of rocks, standardization of instruments, and experiments with model ore-bodies. The field work will be conducted in the vicinity of Golden to demonstrate the operation of instruments.

A complete line of laboratory and field equipment for all geophysical methods is available, including an automatic torsion-balance, vertical and horizontal magnetometers, mechanical and electromagnetic seismographs, and apparatus for resistivity, self potential, equipotential, electromagnetic, and inductive prospecting.

Owing to the nature of the course it will not be possible to take laboratory and field work without lectures and vice versa, and students wishing to take the course must have adequate preparation in undergraduate physics, geology, and mathematics. The course will be given during July 11 to August 20, 1932. The fee for the lectures is $40, for the laboratory and field work, $25. Further information with reference to the course may be obtained by addressing Dr. C. A. Heiland, Colorado School of Mines, Golden, Colorado.

17. *Remodeled magnetograph at Sitka*—At the magnetic observatory at Sitka, Alaska, the old magnetograph was dismounted October 20, 1931, the supporting posts were removed, a new concrete foundation was built extending nearly to the floor-level, marble piers were erected on this foundation, and a remodeled magnetograph was installed, adjusted, and put in operation on November 1.

18. *Repeat-stations in Territory of Hawaii*—Comdr. J. H. Peters of the United States Coast and Geodetic Survey occupied magnetic repeat-stations during May on the Islands of Hawaii, Maui, and Kauai, in the Territory of Hawaii.

19. *Polar Year Station at Jan Mayen*—According to a communication to the journal "Grazer Tagepost" of January 26, 1932, Austria proposes to send an expedition of three scientists (Drs. Tolner, Kanitscheider, and Engineer Kopf) to Jan-Mayen, where Austria maintained a scientific station during the First International Polar Year. On the program of the Expedition, the work of which is to extend over 13 months, are observations of terrestrial magnetism, atmospheric electricity, polar lights, meteorology, etc. The Expedition is being organized by the Vienna Academy of Sciences.

LIST OF RECENT PUBLICATIONS

By H. D. Harradon

A—Terrestrial and Cosmical Magnetism

Batavia. Observations made at the Royal Magnetical and Meteorological Observatory at Batavia, v. 50, 1927. Published by order of the government of the Netherlands Indies, by Prof. Dr. J. Boerema, Director. Batavia, Govt. Printing Office, 1932 (xxii+108 with 3 pls. of curves). 36 cm. [Contains magnetical records Batavia-Buitenzorg for 1927.]

Berlin, Preussisches Meteorologisches Institut. Bericht über die Tätigkeit des Preussischen Meteorologischen Instituts im Jahre 1931. Mit einem Anhang, enthaltend wissenschaftliche Mitteilungen. Berlin, Veröff. met. Inst., Nr. 387, 1932 (112). 25 cm. [Contains reports on atmospheric electricity and terrestrial magnetism, pp. 33-38.]

Bombay and Alibag Observatories. Magnetic, meteorological, and seismographic observations made at the Government Observatories, Bombay and Alibag, in the year 1928, under the direction of S. K. Banerji. With an appendix relating to the climatology of Bombay. Calcutta, Govt. India Central Publication Branch, 1931 (iii+160 with 5 pls.). 34 cm.

Brückmann, W. Erdmagnetische Vermessung der Schweiz. 1. Allgemeines—Deklination. Zürich, Ann. Schweiz. Met. Zentralanst., Jahrg. 1930, 1931 (24 mit 6 Abb. und 2 Karten). 30 cm. [Contains values of the magnetic declination at 134 Swiss stations, together with descriptions of these stations, and a map showing lines of equal magnetic declination in Switzerland for the middle of 1931.]

Čechura, Fr. Magnetická deklinace v zemi Moravsko-slezské pro epochu 1925.5. Praha, Rozpravy II. tř. Ceské Akademie, Roč. 39, Čis. 53, 1929 (30 avec 3 cartes). [La déclinaison magnétique en Moravie-Silésie pour l' époque 1925.5. Texte tchèque avec résumé français. Cet article paraît aussi dans l'Annuaire de l'Institut Géophysique National de la République Tchécoslovaque 1928-1929, Praha, 1931.]

Magneticá deklinace v Čechách pro epochu 1925.5. Cast II. Praha, Rozpravy II. tř. Ceské Akademie, Roč. 39, Čis. 6, 1929. (23 avec 2 cartes). [Déclinaison magnétique en Bohême pour l'époque 1925.5. Texte tchèque avec résumé français. Les résultats des mesures de la déclinaison magnétique effectuées en 1925-1926 sont présentés d'une part par une carte des isogones et d'autre part par les formules empiriques des valeurs de la déclinaison. Cet article paraît aussi dans l' Annuaire de l'Institut Géophysique National de la République Tchécoslovaque 1928-1929, Praha, 1931.]

De Bilt, Meteorological and Magnetic Observatory. Annuaire. Quatre-vingt-deuxième année 1930. B. Magnétisme terrestre. (K. Nederlandsch Met. Inst. No. 98.) Amsterdam, 1931 (ix+24). 34 cm.

Dines, J. S. Meteorological instruments. London, J. Sci. Instr., v. 9, No. 2, 1932 (69-71). [Contains brief description of magnetograph, designed by D. la Cour, comprising *D*, *H*, and *V* variometers with quick-run recording mechanism.]

Eblé, L., et G. Gibault. Valeurs des éléments magnétiques à la station du Val-Joyeux (Seine-et-Oise) au ler janvier 1932. Paris, C.-R. Acad. sci., T. 194, No. 11, 1932 (1008).

Eve, A. S. A magnetic method of estimating the height of some buried magnetic bodies. With discussion. New York, N. Y., Trans. Amer. Inst. Min. Metall. Eng., Geophysical Prospecting, 1932 (200-215).

Fleming, J. A. Time-changes in the Earth's magnetic field. Sci. Mon., New York, N. Y., v. 34, No. 6, 1932 (499-530 with illus.).

Fourmarier, P. Mesure de la direction et de l'intensité du champ magnétique terrestre par induction électromagnétique. Bruxelles, Bul. Acad. roy., Sér. 5, T. 17, No. 6, 1931 (797-807). [Liége, Univ., Inst. Astr. Géod., No. 67, 1931.]

HARANG, L., AND E. TÖNSBERG. Investigations of the aurora borealis at Nordlys Observatoriet, Tromsö 1929-1930. Communications from the Auroral Observatory, Tromsö. Geophys. Pub., v. 9, No. 5, 1932 (50 with 3 pls.).

HAZARD, D. L. Magnetic declination in the United States 1930. Washington, D. C., Dept. Comm., U. S. Coast Geod. Surv., Serial 540, 1932 (40 with 1 chart). [Contains chart showing lines of equal annual change in the United States for 1930.]

HECK, N. H. Military uses of terrestrial magnetism. Military Engineer, Washington, D. C., v. 24, No. 134, 1932 (171-174).

HONGKONG, ROYAL OBSERVATORY. Monthly meteorological bulletin, December, 1931. Containing detailed results of observations made at the Royal Observatory, Hongkong, and the daily weather reports from various stations in the Far East, together with mean monthly and annual values of the principal meteorological elements at Hongkong, typhoon tracks, and results of magnetic observations made in the year 1931. Prepared under the direction of T. F. Claxton, Director. Hongkong, Noronha and Co., 1932 (ca. 60 with map). 33 cm.

KOENIGSBERGER, J. Zu Folgheraiter's Bestimmung des magnetischen Erdfeldes aus der Magnetisierung gebrannter Tongegenstände. Beitr. Geophysik, Leipzig, Bd. 35, Heft 1, 1932 (51-54).

Ueber remanenten Magnetismus von Gesteinen. Beitr. Geophysik, Leipzig, Bd. 35, Heft 2, 1932 (204-216).

KUBO, K. Magnetic survey by the instrument of India Magnetic-Survey Pattern. J. Oceanogr., Kobe, v. 3, No. 2, 1932 (447-476). [Text in Japanese language.]

MERCANTON, P. L. Inversion de l'inclinaison magnétique aux âges géologiques. Nouvelles constatations. Paris, C.-R. Acad. sci., T. 194, No. 16, 1932 (1371-1372).

MERKEN, MLLE M. Sur la répartition du magnétisme terrestre en Belgique. Liége, Univ., Inst. Astr. Géod., No. 55, 1931 (8 avec 2 figs.).

MOIDREY, J. DE. Etudes sur le magnétisme terrestre à Zi-ka-wei et Lu-kia-pang 1877-1929, résumées par J. de Moidrey. Fascicule IX. Shanghai, Imprimerie de la Mission Catholique, 1932 (24 avec 6 pls.). 31 cm. [Ce fascicule contient l'Etude 39 intitulée "Variation séculaire des éléments magnétiques en Extrême-Orient."]

NIPPOLDT, A. Vorschläge zur magnetischen Orientierung in eisenhaltigen Gruben. (Im Anhang, Bericht Preuss. met. Inst., 1931.) Berlin, Veröff. met. Inst., Nr. 387, 1932 (98-102).

SCHLOMKA, T. Zur Haalckschen Theorie des Erdmagnetismus. Mit Erwiderung von H. Haalck. Zs. Geophysik, Braunschweig, Jahrg. 8, Heft 1/2, 1932 (84-88).

ŠPAČEK, V. Stanovení azimutu při podrobném měření magnetické deklinace. Zeměměřicskéy Věstnik, Brno, cis. 7, 1930 (4). [La détermination de l' azimut dans la mesure détaillée de la déclinaison magnétique. Texte tchèque avec résumé français.]

ŠPAČEK, V., ET B. ZAHÁLKA. Magnetismus Řípu. Praha, Rozpravy II. tř. Ceské Akademie, Roč. 39, Čis. 48, 1929 (15 avec 1 carte). [Magnétisme du Rip. Texte tchèque avec résumé français.]

STEARN, N. H. Practical geomagnetic exploration with the Hotchkiss superdip. With discussion. New York, N. Y., Trans. Amer. Inst. Min. Metall. Eng., Geophysical Prospecting, 1932 (169-199).

STENZ, E. Bericht über die magnetischen Arbeiten des geophysikalischen Instituts Lwów, 1928-1930. Beitr. Geophysik, Leipzig, Ergänzungshefte, Bd. 2, Heft 4, 1932 (409-426).

VEDY, L. G. On the determination of the horizontal component of the Earth's magnetic field by a coupled oscillations method. Cambridge, Proc. Phil. Soc., v. 28, Pt. 1, 1932 (109-114). [An account is given of a simple experiment designed to illustrate quantitatively the phenomena of coupled oscillations. Two similar small magnets are suspended in the Earth's magnetic field at a suitable distance apart so that there is appreciable magnetic interaction between the two oscillatory systems. Under the conditions employed, the equations of motion reduce to a simple form, and the experiment may be used as a method of measuring the intensity of the horizontal component of the Earth's magnetic field.]

ZI-KA-WEI, OBSERVATOIRE DE. Observations magnétiques faites à l' Observatoire de Lu-kia-pang. Tome XV. Années 1927-1928. Zi-ka-wei—Chang-hai, Imprimerie de la Mission Catholique, 1932, 57 pp. 31 cm.

B—Terrestrial and Cosmical Electricity

Appleton, E. V., and Others. Upper air ionisation. Observatory, London, v. 55, No. 694, 1932 (75-81). [Summary of the Geophysical Discussion which was held in the rooms of the Royal Astronomical Society, London, Jan. 29, 1932.]

Bauer, W. Ultrarote Nordlichtphotographie. Naturw., Berlin, Jahrg. 20, Heft 16, 1932 (287-288).

Bernardini, G. The variation of penetrating-radiation with zenith-distance. Nature, London, v. 129, Apr. 16, 1932 (578-579).

Bureau, R. Variation diurne des atmosphériques à Paris de 1928 à 1931. Influences respectives des sources et de la propagation. Paris, C.-R. Acad. sci., T. 194, No. 16, 1932 (1368-1370).

Chapman S. Polar lights. Nature, London, v. 129, June 4, 1932 (820-821). [Substance of a lecture delivered at the annual meeting of the British Science Guild, May 25, 1932.]

Compton, A. H., R. D. Bennett, and J. C. Stearns. Ionization by penetrating-radiation as a function of pressure and temperature. Phys. Rev., Menasha, Wis., v. 39, No. 6, 1932 (873-882).

Corlin, A. Measurements of the cosmic ultra-radiation in Northern Sweden. Lund, Obs. Cir. No. 6, Mar. 25, 1932 (124-132 with 4 figs.).

Dauvillier, A. Recherches de physique cosmique. J. Physique et Le Radium, Paris, T. 3, No. 2, 1932 (21 S—24 S). [This communication which deals with an attempt to obtain a synthetic interpretation of the electromagnetic phenomena produced on the earth by electronic radiation from the Sun, is followed by remarks by Ch. Maurain. See also Rev. gén. électr., Paris, v. 31, 5 mars, 2 et 9 avril 1932.]

Ehrenburg, D. O., and R. J. Watson. Mathematical theory of electrical flow in stratified media with horizontal, homogeneous and isotropic layers. With discussion. New York, N. Y., Trans. Amer. Inst. Min. Metall. Eng., Geophysical Prospecting, 1932 (423-442).

Ertel, H. Zur Theorie des Erdstroms. (Im Anhang, Bericht Preuss. met. Inst., 1931.) Berlin, Veröff. met. Inst., Nr. 387, 1932 (105-109).

French, C. A. Magnetic survey of the Hull-Gloucester and Hazeldean faults. Ottawa, Dept. Mines, Geol. Surv., Mem. 165, 1931 (210-225).

Gilchrist, L. Experiments in electrical exploration made in the summer of 1929. Ottawa, Dept. Mines, Geol. Surv., Mem. 165, 1931 (161-189). [The results of the following investigations are presented: (1) Electrical investigations at the Abana mine in northwestern Quebec: (a) Measurements of resistivity by the Wenner-Lee method with a megger, and (b) measurements of resistivity by the central electrode method with a megger. (II) Electrical investigations at the Falconbridge mine. Measurements of resistivity by the central electrode method with: (a) a megger, (b) a milliammeter and potentiometer. (III) Electrical investigations at the Errington or Treadwell-Yukon mine. Measurements of resistivity by the central electrode method with a milliammeter and potentiometer. (IV) Magnetic investigations at the Falconbridge mine and the Errington mine. A magnetometer exploration with the Toberg magnetometer.]

Gilchrist, L., and J. B. Mawdsley. Investigations made in cooperation with Radiore Company of Canada, Limited, Schlumberger Electrical Prospecting Methods, and Swedish American Prospecting Company of Canada. Ottawa, Dept. Mines, Geol. Surv., Mem. 165, 1931 (1-77). [This report based on field work carried out by the Canadian Geological Survey in conjunction with companies using electrical methods, is an attempt to meet the general demand for unbiased information concerning prospecting by electrical methods.]

Gish, O. H. Systematic errors in measurements of ionic content and the conductivity of the air. Beitr. Geophysik, Leipzig, Bd. 35, Heft 1, 1932 (1-5).

Hahnfeld, I. Untersuchungen über die elektrische Raumladung und das elektrische Feld am Boden. Zs. Geophysik, Braunschweig, Jahrg. 8, Heft 1/2, 1932 (89-106). [Ein Instrument zur automatischen Registrierung der Erdoberflächenladung wurde konstruiert, Parallelregistrierungen von Luftpotential, Raumladung, und

Oberflächenladung ausgeführt. Die Theorie der Instrumente wurde diskutiert, sodann auf Grund der Potentialtheorie aus den Beobachtungen eine Raumladungschicht am Boden nachgewiesen und ihre Dicke (wenige Meter) errechnet. Innerhalb dieser lässt sich unmittelbar am Boden eine zweite, wenige Dezimeter dicke Schicht von zehnmal höherer Raumladungsdichte vermuten.]

Hubbert, M. K. Results of earth-resistivity survey on various geologic structures in Illinois. New York, N. Y., Amer. Inst. Min. Metall. Eng., Tech. Pub. No. 463, 1932 (23 with 12 figs.).

Hulburt, E. O. Tables of the ionization in the upper atmosphere. Phys. Rev., Menasha, Wis., v. 39, No. 6, 1932 (977-992). [Continuing the work on the ionization of the upper atmosphere, this paper takes into account as far as possible the entire meteorology of the upper atmosphere and the effects of recombination, temperature diffusion, and the motions of the ions and electrons in the gravitational, electric, and magnetic fields of the Earth. Tables are presented of the ion and electron densities over the Earth. After sunset as a result of temperature diffusion and electro-magnetic drift, the ionized region separates into two banks, one with a maximum of ionization at about 110 km and one with a maximum at about 140 km. Quantitative agreement is found with the skip distances and other phenomena of wireless waves and with various facts of terrestrial magnetism.]

Hummel, J. N. A theoretical study of apparent resistivity in surface potential methods. New York, N. Y., Trans. Amer. Inst. Min. Metall. Eng., Geophysical Prospecting, 1932 (392-422).

Humphreys, W. J. White lightning versus red as a fire hazard. Washington, D. C., Mon. Weath. Rev., v. 59, No. 12, 1931 (481). [Brief note in which the author concludes that it is not the difference between white lightning and red lightning that makes the one a greater fire hazard than the other, but the condition, wet or dry, of the combustible matter when struck.]

Kelly, S. A uniform expression for resistivity. New York, N. Y., Trans. Amer. Inst. Min. Metall. Eng., Geophysical Prospecting, 1932 (141-143).

Kimpara, A. Correlation of atmospherics with thunderstorms. Radio Res. Japan, Rep. 1, 1931 (127-150). Abstr., Sci. Abstr., London, v. 35, No. 410, 1932 (146).

Kolhörster, W. Zur Prüfung der Theorie des vertikalen Zählrohreffekts der Höhenstrahlung. Berlin, SitzBer. Akad. Wiss., Nr. 5, 1932 (39-43. mit einer Tafel).

Vertical tube counter- and the barometer-effect of cosmic radiation at sea-level. Nature, London, v. 129, Mar. 26, 1932 (471).

Kramer J. B. The early history of magnetism. Paper read at a meeting of the Newcomen Society held at the British Industries Fair, Birmingham, England, March 2, 1932. Note regarding subject matter in Nature, London, v. 129, Mar. 19, 1932 (428-429).

Leonardon, E. G. Topographical study of a hidden bedrock surface by resistivity-methods. Eng. J., Montreal, v. 14, No. 6, 1931 (331-335).

Electrical exploration applied to geological problems in civil engineering. New York, N. Y., Trans. Amer. Inst. Min. Metall. Eng., Geophysical Prospecting, 1932 (99-113).

Lindholm, F. Ueber die Intensitätsvariationen der kosmischen Ultrastrahlung. Beitr. Geophysik, Leipzig, Bd. 35, Heft 2, 1932 (224-229).

Locher, G. L. Cosmic-ray particles. Phys. Rev., Menasha, Wis., v. 39, No. 6, 1932 (883-888).

Low, B., S. F. Kelly, and W. B. Creagmile. Applying the Megger ground tester in electrical exploration. With discussion. New York, N. Y., Trans. Amer. Inst. Min. Metall. Eng., Geophysical Prospecting, 1932 (114-126).

Lundberg, H., and T. Zuschlag. A new development in electrical prospecting. New York, N. Y., Trans. Amer. Inst. Min. Metall. Eng., Geophysical Prospecting, 1932 (47-62). [A new measuring procedure permitting potential drop ratio determinations is described. Following a brief nontechnical discussion of some fundamental applications, the results of four actual investigations of different types are discussed.]

McLennan, J. C., H. S. Wynne-Edwards, and H. J. C. Ireton. Height of polar aurora in Canada. Ottawa, Can. J. Res., v. 5, 1931 (285-296). [Simultaneous photographs were made at two stations in northern Ontario, Canada, and from them a number of values for the height and position were obtained. For the lower limits of arcs and bands these ranged between 70 and 130 km with a maximum frequency between 90 and 95 km. The mean height for all such lower limits was 95 km.]

Messerschmidt, W. Ueber die sonnenzeitliche Periode der harten Ultrastrahlung. Zs. Physik, Berlin, Bd. 74, Heft 3/4, 1932 (187-190).

Zur sonnenzeitlichen Periode der Ultrastrahlung. Physik. Zs., Leipzig, Jahrg. 33, Nr. 6, 1932 (233-234).

Müller, H. G. Zur Frage der Aufladungsgeschwindigkeit von Stratuswolken. Beitr. Geophysik, Leipzig, Bd. 33, 1931 (125-129).

Nolan, J. J., and J. G. O'Keeffe. Electric discharge from water drops. Dublin, Proc. R. Irish Acad., A, v. 40, No. 5, 1932 (86-98). [Summary: The discharge from water drops originally hemispherical is investigated. It is shown that the negative always exceeds the positive current for the same field values. The value of the uniform field at which rapid discharge sets in at a suspended drop is connected with the radius of the drop by the approximate relation $F\sqrt{r}=3.6\times10^3$. The ions produced by the discharge remain small ions in pure air, but in the presence of condensation nuclei readily form multiply charged large ions by attachment.]

Nukiyama, D. A further contribution to the theory of thunderclouds. Jap. J. Astr. Geophys., Tokyo, v. 9, No. 2, 1932 (101-113).

Oliver, J. F. Observation of aurora at Aberdeen, March 28th, 1932. Met. Mag., London, v. 67, No. 795, 1932 (63-64).

Ollendorff, F. Der Einfluss des Erdwiderstandes auf den Blitz. Physik. Zs., Leipzig, Jahrg. 33, Nr. 9, 1932 (368-376).

Peters, L. J., and J. Berdeen. Some aspects of electrical prospecting applied in locating oil structures. Physics, Menasha, Wis., v. 2, No. 3, 1932 (103-122).

Poser, H. Zwei Nordlichtbeobachtungen zwischen Jan Mayen und Island im August-September 1931. Met. Zs., Braunschweig, Bd. 49, Heft 3, 1932 (122-123).

Ramanathan, K. R., and J. V. Karandikar. Non-polar auroral light from the night sky in the tropics. Nature, London, v. 129, Apr. 9, 1932 (545).

Ratcliffe, J. A., and F. W. G. White. Polarisation of downcoming wireless waves. Nature, London, v. 129, Mar. 5, 1932 (364).

Regener, E. Ueber das Spektrum der Ultrastrahlung. I. Die Messungen im Herbst 1928. Zs. Physik, Berlin, Bd. 74, Heft 7/8, 1932 (433-454). [Es wird über die Messung der Absorption der Ultrastrahlung im Bodensee bis 230 m Tiefe berichtet. Das dazu benutzte versenkbare Registrierelektrometer gibt bei feststehender photographischer Platte eine sehr gesteigerte Messgenauigkeit. Der festgestellte durchdringendste Anteil der Ultrastrahlung ist von etwa 80 m Wassertiefe an wahrscheinlich homogen und hat dann, ohne Streustrahlung und für parallele Inzidenz gerechnet, einen Absorptionskoeffizienten von 1.9×10^{-4}/cm H_2O. Seine Wellenlänge entspricht wahrscheinlich der Zerstrahlung der Masse eines Heliumatoms.]

Rossi, B. Nachweis einer Sekundärstrahlung der durchdringenden Korpuskularstrahlung. Physik. Zs., Leipzig, Jahrg. 33, Nr. 7, 1932 (304-305).

Schlumberger, C., and M. Schlumberger. Depth of investigation attainable by potential methods of electrical exploration. New York, N. Y., Trans. Amer. Inst. Min. Metall. Eng., Geophysical Prospecting, 1932 (127-133).

Electrical studies of the Earth's crust at great depths. New York, N. Y., Trans. Amer. Inst. Min. Metall. Eng., Geophysical Prospecting, 1932 (134-140).

Schlumberger, C., M. Schlumberger, and E. G. Leonardon. Electrical coring; a method of determining bottom-hole data by electrical measurements. New York, N. Y., Amer. Inst. Min. Metall. Eng., Tech. Pub. No. 462, 1932 (38 with 22 figs.).

Location and study of pipe-line corrosion by surface electrical measurements. New York, N. Y., Amer. Inst. Min. Metall. Eng., Tech. Pub. No. 476, 1932 (24 with 16 figs.).

STEINKE, E. G., UND H. SCHINDLER. Zertrümmerung von Blei durch Ultrastrahlung. Zs. Physik, Berlin, Bd. 75, Heft 1/2, 1932 (115-118).

SUNDBERG, K. Effect of impregnating waters on electrical conductivity of soils and rocks. New York, N. Y., Trans. Amer. Inst. Min. Metall. Eng., Geophysical Prospecting, 1932 (367-391).

TAGG, G. F. Interpretation of resistivity-measurements. New York, N. Y., Amer. Inst. Min. Metall. Eng., Tech. Pub. No. 477, 1932 (13 with 7 figs.).

TUWIM, L. Grundzüge einer mathematischen Theorie der Höhenstrahlungskoinzidenzen in Zählrohren. Berlin, SitzBer. Ak. Wiss., No. 33, 1931 (830-949).

VEGARD, L. Spektralaufnahmen von ultraroten Linien im Nordlichtspektrum. Naturw., Berlin, Jahrg. 20, Heft 15, 1932 (268-269).

Spectrographic observations of infra-red lines in the auroral spectrum. Nature, London, v. 129, Mar. 26, 1932 (468).

VENSKE, O. Die Bedeutung von Erdstrombeobachtungen. (Im Anhang, Bericht Preuss. met. Inst., 1931.) Berlin, Veröff. met. Inst., Nr. 387, 1932 (102-105).

WAIT, G. R., AND O. W. TORRESON. Rate of ionisation of the atmosphere. Nature, London, v. 129, Mar. 12, 1932 (401-402).

WALTER, B. Ueber den Unterschied in der Blitzgefahr der Eiche und der Buche. Physik. Zs., Leipzig, Jahrg. 33, Nr. 7, 1932 (306-307).

ZUSCHLAG, T. Mapping oil structures by the Sundberg method. With discussion. New York, N. Y., Trans. Amer. Inst. Min. Metall. Eng., Geophysical Prospecting, 1932 (144-159).

C—Miscellaneous

APPLETON, E. V., AND F. W. CHAPMAN. The collisional friction experienced by vibrating electrons in ionized air. London, Proc. Phys. Soc., v. 44, No. 243, 1932 (246-254).

BARRET, W. M. A method for determining magnetic susceptibility of core-samples. With discussion. New York, N. Y., Trans. Amer. Inst. Min. Metall. Eng., Geophysical Prospecting, 1932 (216-236).

BERKNER, L. V. Some studies of radio transmission over long paths made on the Byrd Antarctic Expedition. Washington, D. C., Bur. Stan. J. Res., v. 8, No. 2, 1932 (265-278). [Correlation with magnetic activity is discussed, pp. 276-277.]

BERLIN, PREUSSISCHE AKADEMIE DER WISSENSCHAFTEN. Adresse an Hrn. Adolf Schmidt in Gotha zum fünfzigjährigan Doktorjubilaum am 20. Marz 1932. Berlin, SitzBer. Ak. Wiss., Nr. 11, 1932 (75-76).

BIRKELAND, B. J., UND N. J. FÖYN. Klima von Nordwesteuropa und den Inseln von Island bis Franz-Josef-Land. Berlin, Verlag von Gebrüder Borntraeger, 1932 (vii+124). 26 cm. [Bd. 2, Teil L, Handbuch der Klimatologie, herausgegeben von W. Köppen und R. Geiger.[

BOCK, R. Ueber einige praktische Erfahrungen mit der galvanischen Waage. (Im Anhang, Bericht Preuss. met. Inst., 1931.) Berlin, Veröff. met. Inst., Nr. 387, 1932 (109-110).

BOTSET, H. G., AND P. WEAVER. Radon content of soil gas. Physics, Menasha, Wis., v. 2, No. 5, 1932 (376-385).

BRAAK, C. Klimakunde von Hinterindien und Insulinde. Berlin, Verlag von Gebrüder Borntraeger, 1931 (iv+125 mit 29 Karten und 2 Diagrammen). 26 cm. [Bd. 4, Teil R, Handbuch der Klimatologie, herausgegeben von W. Köppen und R. Geiger.]

C., S. Dr. L. A. Bauer. Nature, London, v. 129, May 14, 1932 (715). [Obituary.]

CHADWICK, J. Possible existence of a neutron. Nature, London, v. 129, Feb. 27, 1932 (312).

CHARCOT, J. B., L'année polaire. Terre Air Mer, Paris, T. 57, No. 5, 1932 (337-355). [Concerned chiefly with the French participation in the International Polar Year 1932–33.]

DeGolyer, E. Choice of geophysical methods in prospecting for oil deposits. With discussion. New York, N. Y., Trans. Amer. Inst. Min. Metall. Eng., Geophysical Prospecting, 1932 (1-23). [Magnetic and electrical methods are discussed.]

Egedal, J. Ueber eine Messung der Bewegung von Pfeilern. Zs. Geophysik, Braunschweig, Jahrg. 8, Heft 3/4, 1932 (195-196).

Estrafallaces, A. I nuclei di condensazione del vapore nell' atmosfera. Meteor. Prat., Subiaco, Anno 13, No. 1, 1932 (2-9).

Eve, A. S. Absorption of electromagnetic induction and radiation by rocks. New York, N. Y., Trans. Amer. Inst. Min. Metall. Eng., Geophysical Prospecting, 1932 (160-168).

Eve, A. S., D. A. Keys, H. C. I. Watson, J. H. Swartz, and J. B Mawdsley. Geophysical investigations at the Mammoth Caves, Kentucky, and in the Sudbury Basin District, Ontario. Ottawa, Dept. Mines, Geol. Surv., Mem. 165, 1931 (78-160). [The work in applied geophysics consisted in an endeavor to attack and solve certain definite problems. In the report each problem is stated, the method used and apparatus employed quoted, and the answer to the problem, at least in the present state of our knowledge, is given with suggestions as to future investigations.]

F[leming], J. A. Louis Agricola Bauer, 1865-1932. Science, New York, N. Y., N. S., v. 75, No. 1948, 1932 (452-454).

Glanville, W. E. Zodiacal light notes. Pop. Astr., Northfield, Minn., v. 40, 1932 (118-119; 240-241; 311-313).

Gutenberg, B. Handbuch der Geophysik. Herausgegeben von B. Gutenberg. Berlin, Verlag von Gebrüder Borntraeger, 26 cm. Band 1, Lieferung 1, 1931 (vii+308 mit 41 Abb.). [B. Gutenberg, Einleitung: Allgemeines über Geophysik, 1-7; F. Nölke, Die Entwicklung des Sonnensystems und der Erde, 8-68; M. Milankovitch, Stellung und Bewegung der Erde im Weltall, 69-138; F. Hopfner, Figur der Erde, Dichte und Druck im Erdinnern, 139-308.] Band 2, Lieferung 1, 1931 (viii+564 mit 183 Abb.). [B. Gutenberg, Abkühlung und Temperatur der Erde, 1-35; G. Berg, Chemie der Erde, 36-189; A. Born, Alter der Erde und geologische Zeitalter, 190-439; B. Gutenberg, Der physikalische Aufbau der Erde, 440-564.] Band 3, Lieferung 1, 1930 (ix+570 mit 207 Abb.). [B. Gutenberg, Kräfte in der Erdkruste, 1-31; F. von Wolff, Plutonismus und Vulkanismus, 32-348; A. Born, Erdkrustenbewegungen, 349-441; B. Gutenberg, Geotektonische Hypothesen, 442-547; H. Hess, Mechanische Wirkungen von Eis, Wasser und Wind auf die Erdkruste, 548-570.] Band 6, Lieferung 1, 1931 (v+312 mit 134 Abb.). [H. Reich, Eigenschaften der Gesteine, 1-83; H. Hunkel, Die Elektrischen Aufschlussmethoden, 84-165; E. A. Ansel, Theorie der gravimetrischen Aufschlussmethoden, 166-235; O. Meisser, Instrumente der gravimetrischen Aufschlussmethoden, 236-312.]

Heidke, P. Das Zweite Internationale Polarjahr 1932-33. Ann. Hydrogr., Hamburg, Jahrg. 60, 1932 (81-93 mit 1 Taf.).

International Astronomical Union. Character-figures of solar phenomena 1923–1928. Vol. 1. Published by the Eidgen. Sternwarte in Zürich. Zürich, Gebr. Leemann und Co., 1932 (78 with 3 pls.). 31 cm. [Fig. 8 shows a comparison between character figures for solar phenomena and terrestrial magnetic activity.]

International Meteorological Organization. Procès-verbaux des séances du Comité Meteorologique International à Locarno, octobre 1931, et rapports de 3 commissions et d'une sous-commission à Innsbruck et Locarno, septembre et octobre 1931. Leyde, Imprimerie Edouard Ijdo, 1932 (ii+385 avec figs. et 1 carte.). 24 cm. [Contains the proceedings of the meetings of the Commission for the Polar Year 1932-1933, at Innsbruck, September 23-26, 1931, pp. 59-241, and of the Commission for Terrestrial Magnetism and Atmospheric Electricity at Innsbruck, September 21-23, 1931, pp. 242-281.]

Israël, H. Zum Problem der Randstörungen bei Ionenmessungen. Beitr. Geophysik, Leipzig, Bd. 35, Heft 3/4, 1932 (341-348).

Jakosky, J. J., C. H. Wilson, and J. W. Daly. Geophysical examination of Meteor Crater, Arizona. With discussion. New York, N. Y., Trans. Amer. Inst. Min. Metall. Eng., Geophysical Prospecting, 1932 (63-98 with 6 figs.). [The purpose of

the geophysical work described in this paper was to obtain information as to the advisability of continuing exploratory work at the Crater and the direction such work should take. Three main independent studies were carried out: (1) geological, (2) electrical, and (3) magnetic. A general report on the results is given.]

Kennelly, A. E. Recent developments in magnetic units. Elec. Eng., New York, N. Y., v. 51, No. 5, 1932 (343-345). [To overcome confusion in the use of electromagnetic units, the International Electrotechnical Commission through its subcommittee on electric and magnetic magnitudes and units has been working for several years toward standardization in definition and nomenclature. In this article, recent actions in that direction are discussed and a brief summary of earlier contingent actions is given.]

London, Department of Scientific and Industrial Research. The investigation of atmospheric pollution. Report on observations in the year ended 31st March, 1931. Seventeenth report. London, H. M. Stationery Office, 1931 (vii+110). 28 cm.

Mount Wilson Observatory. Summary of Mount Wilson magnetic observations of sunspots for January and February, 1932. Pub. Astr. Soc. Pacific, San Francisco, Cal., v. 44, 1932 (125-127).

Neumann, F., and R. R. Bodle. United States earthquakes 1930. Washington, D. C., Dept. Comm., U. S. Coast Geod. Surv., Ser. No. 539, 1932 (ii+25). 23 cm.

Roman, I. Least squares in practical geophysics. New York, N. Y., Trans. Amer. Inst. Min. Metall. Eng., Geophysical Prospecting, 1932 (460-506).

Sapper, K. Klimakunde von Mittelamerika. Berlin, Verlag von Gebrüder Borntraeger, 1932 (iii+74). 26 cm. [Bd. 2, Teil L, Handbuch der Klimatologie, herausgegeben von W. Köppen und R. Geiger.]

Slichter, L. B. Observed and theoretical electromagnetic model response of conducting spheres. New York, N. Y., Trans. Amer. Inst. Min. Metall. Eng., Geophysical Prospecting, 1932 (443-459).

Stearns, J. C., and W. Overbeck. Factors influencing ionization produced by cosmic and gamma rays. Phys. Rev., Menasha, Wis., v. 40, No. 4, 1932 (636-637).

Wang, K. C. Atmospheric radioactivity and Peiping weather. Peiping, Sci. Rep., Tsing Hua Univ., A, v. 1, No. 3, 1931 (119-128)

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